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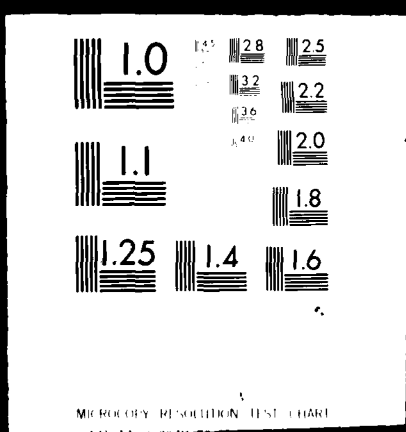

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Three experiments examining individual differences in multiple-task performance are presented. Experiment I examined whether the response strategies used to perform two discrete information processing tasks reflected individual differences in information processing at high levels of workload or simply were selected at random. Each subject's response strategy first was identified as either a simultaneous, an alternating, or a massed strategy. Then some of the subjects were asked to change strategy. The results indicated that the massed response strategy subjects had less

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20. well developed timesharing skills and were not able to process information under multiple-task conditions as well as the other subjects regardless of the response strategy used. The results were interpreted as evidence that response strategies represent fundamental differences in multiple-task information processing.

Experiments II and III attempted to locate the source of the differences observed in Experiment I. Experiment II examined the relation between multiple-task performance in two different task combinations and cerebral lateralization, multiple-limb coordination, and four tests of cognitive style. No significant relations were found.

In Experiment III each subject's response strategy first was identified. The subjects then were asked to perform a discrete task combination consisting of a classification task and a choice reaction time task. Estimates of the duration of various processing stages were obtained from the choice reaction time data. Analyses revealed that the duration of information processing stages did not differ significantly between strategy groups.

A general interpretation of the data and recommendations for future research are given.

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February 1981

RESPONSE STRATEGIES AND INDIVIDUAL DIFFERENCES IN MULTIPLE-TASK PERFORMANCE

Grant No. AFOSR- 790014

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Prepared for
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FOREWORD

This final report presents the results of three experiments done in the period October 1, 1978 to February 28, 1981. These experiments were sponsored by the Air Force Office of Scientific Research Grant No. AFOSR -79-0014 [redacted]. The original title of this grant was Training Efficient Multiple-Task Processing Strategies. Dr. Jack Thorpe was the program manager; Dr. Diane Damos was the principal investigator. The majority of the work was conducted at the Department of Industrial Engineering, The State University of New York at Buffalo. The remainder of the work was accomplished at the Department of Psychology, University of Oregon.

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INTRODUCTION

This report presents the results of three experiments examining individual differences in multiple-task performance. These differences originally were observed by Damos and Wickens (1980) who found large differences in performance on a discrete task combination associated with the response strategy used to perform the combination. The investigators found that each subject's strategy could be easily classified as a "simultaneous," an "alternating," or a "massed" strategy. The subjects using a simultaneous response strategy responded to both stimuli within some small interval (typically less than 10 msec). Those using an alternating response strategy alternately made one response to each task while the subjects using a massed strategy consistently made more than two consecutive responses to the same task. Interestingly enough, there was some evidence of between-group differences in performance on a combination consisting of two tracking tasks as well as on the discrete task combination. Damos and Wickens offered two possible explanations for these results. First, the response strategy simply was selected at random but had a very large effect on all subsequent dual-task performance. Second, the strategy reflected some type of individual difference in information processing under multiple-, but not single-, task conditions.

The implications of the results described above, if they are generalizable, are obvious: If a response strategy is simply selected at random then subjects may be trained to use an efficient strategy, thereby improving their performance. If, on the other hand, the response strategy reflects some type of individual difference in information processing at high levels of workload, then subjects should, and can, be selected for jobs which require rapid processing of large amounts of data, such as often occurs during flying.

The first experiment described in this report determined if the response strategy reflected true individual differences in information processing by asking subjects to change strategy. The results of Experiment I and another study completed at approximately the same time (Damos and Smist, 1980) indicated that the strategy does reflect some type of individual difference in information processing under multiple-, but not single-, task conditions.

Two possible explanations for these results were postulated. First, the response strategy somehow was related to one or more cognitive styles known to affect information processing or, second, the duration of various information processing stages was different for subjects employing different strategies. The first hypothesis was tested in Experiment II which examined whether the response strategies were related to any of four cognitive styles, cerebral lateralization, or limb coordination. No significant relations were found.

The second hypothesis was tested in Experiment III by examining performance on a choice reaction time task at 1-, 2-, and 3-bits of information under single- and dual-task conditions. The Hick-Hyman Law (Hick, 1952; Hyman, 1953) then was used to estimate slopes and intercepts for each strategy group. No significant between-group differences were found for either measure.

This report is divided into three major subsections corresponding to each of the three experiments. A section giving general conclusions follows Experiment III.

EXPERIMENT I

Experimental Rationale

One way to determine if different response strategies reflect fundamental differences in information processing or are simply selected at random is to ask the subject to change strategies. Such a change should result in a minimal disruption in performance if the "natural" strategy is simply selected at random but should disrupt performance severely if the strategy reflects fundamental differences in an information processing "style." However, a large disruption in performance also may occur if the subject attempts to adopt a new strategy after extensive practice with another. Therefore, to prevent an ambiguous result, it is important to provide only enough practice trials to identify the natural response strategy. Previous research (Damos and Smist, 1980; Damos and Wickens, 1980) indicated that the natural strategy could be identified after five 1-min dual-task trials but that some percentage of subjects, approximately 5-10%, would be misclassified. This percentage was considered acceptably low and response strategy was determined on the basis of performance during five 1-min trials.

Practically, there appeared to be no reason to examine changes from more efficient to less efficient response strategies because there are no real-world situations where the timesharing efficiency of an operator would be degraded deliberately. Thus, subjects always were asked to change to a more efficient response strategy, i.e. from a massed response strategy to a simultaneous response strategy.

Method

Tasks

Classification (CL). For this task two randomly selected digits between five and eight were presented simultaneously to the subject. The digits varied on two dimensions: size and name. The subject determined the number of dimensions on which the stimuli were alike and then pressed one of three keys on his left-hand keyboard. As soon as the subject pressed a key, the pair was erased and a new pair presented 2 msec later.

Two dependent variables were calculated for each trial: the average interval between correct responses (CRI) and the percentage of correct responses to the total number of responses emitted. The average CRI differs from the more common average reaction time in that incorrect responses are not counted in its calculation. That is, when an incorrect response occurs, the CRI is the time between the preceding correct response and the next correct response including the time during which the incorrect response was made. Both the percentage of correct responses and the CRI were displayed to the subject at the end of each single- and dual-task trial. Under single-task conditions the display subtended a visual angle of 0.22° by 0.36°.

Memory (ME). In this task randomly selected digits between one and four were presented sequentially to the subject. The subject retained the most recently displayed digit in memory while responding to the preceding digit. For example, if the first stimulus were "1" and the second "3," the correct response to the "3" would be "1." Responses were made by pressing one of four keys on the right-hand keyboard. The keys were numbered from left to right beginning with "1." The response to the first stimulus of any trial was always "1." As soon as a response was made, the stimulus was erased and the next one was presented.

Two dependent variables were recorded: CRI and the percentage of correct responses. At the end of each single- and dual-task trial the CRI and the percentage of correct responses were displayed to the subject. Under single-task conditions the stimulus subtended a visual angle of 0.22° by 0.14°. Under dual-task conditions the digits for the CL task were presented on the left side of the display screen; the digit for the ME task was presented on the right side. The visual angle subtended by the display was 0.72° by 0.22°.

Apparatus

A Processor Technology Microcomputer with a Helios II disc system recorded all responses and performed all timing. This system also displayed all inputs on a KOYO Model TMC-9M CRT. Two identical 4 by 4 matrix-type Microswitch Model SW-10196 keyboards were mounted into a table in front of the subject. The subject indicated his response by pressing a key on the appropriate keyboard. None of the keys which were used had any identifying marks which would connect them to the stimuli.

Procedure

Day 1. When the subject arrived, he was asked to read a briefing sheet describing the experiment and to sign an informed consent form. After a test of binocular near-vision acuity was completed, the subject was taken to the experimental room and seated approximately 92 cm from the display. The experimenter randomly selected the starting task and played taped instructions describing the task (see Appendix A) to the subject who then performed one trial of the task. Subsequently, he heard taped instructions for the second task and performed one trial of that task. The subject then alternated performing

each of the two tasks alone for ten additional trials. After the 12 single-task trials were completed, the subject heard a tape (see Appendix A) describing the dual-task combination and performed five dual-task trials followed by one trial on each task alone. This testing session required approximately 1.25 hours.

Day 2. The subject first was reminded of the instructions for each task and then alternated performing each task alone for a total of four trials, beginning with the same task as on the preceding day. The experimenter then played taped instructions describing the response strategy the subject was to use on all dual-task trials (see Appendix B). The subject subsequently performed five blocks of trials consisting of five dual-task trials followed by one trial on each task alone. After the subject completed the fifth block, he was debriefed and paid. This session required approximately 1.75 hours.

All trials on both days were 1 min long with a 1-min rest pause between trials. Feedback was displayed to the subject during the rest pause. Additionally, a 2-min rest break was given between Blocks 1 and 2 and 3 and 4 on Day 2. A longer break of 5 min was given between Blocks 2 and 3 and 4 and 5.

Design

A five-group split-plot factorial design (Kirk, 1968) was used on Day 2. Subjects were assigned to one of the five groups on the basis of the response strategy used to perform the ME-CL combination on Day 1. All of the subjects using a simultaneous response strategy on Day 1 were asked to continue using that strategy on Day 2 (Sim-Sim) (n=8). The alternating and massed strategy subjects were assigned to their Day 2 groups at random with the restriction that approximately half of each group be assigned to each of the Day 2 strategies.

Thus, one-half of the subjects using the alternating strategy were asked to continue that strategy on Day 2 (Alt-Alt) (n=3); the other half were asked to use a simultaneous strategy (Alt-Sim) (n=4). Similarly, about one-half of the massed subjects were asked to change to an alternating strategy (Mass-Alt) (n=12); the other half, to a simultaneous strategy (Mass-Sim) (n=10).

Subjects

A total of 54 right-handed subjects were recruited through advertisements placed in the student newspaper and in university buildings. All subjects were between the ages of 18 and 35 and were native English speakers. None had any flight training. Before each subject began the experiment, his vision was tested. No subject was allowed to participate with vision less than 20/20.

All subjects were paid $2.50/hour for participating. The three subjects in each of the five Day 2 groups having the first, second, and third best overall dual-task performance were given bonuses of $10.00, $6.00 and $4.00 respectively.

After the first seven subjects had completed the experiment, a software error was detected and the data for all seven subjects were discarded. Hardware failures caused the loss of three additional subjects' data. The data from three more subjects were discarded because non-standard procedures were used in the course of the experiment. One subject had to be excused because of illness and the Day 1 strategy of three others did not permit them to be assigned to strategy groups (see the Results Section). Thus, a total of 37 subjects completed the experiment and had useable data.

Results

All of the analyses of variance (ANOVA) described in this section were examined for violations of the assumption of homogeneity of variance using the F_{max} test (Kirk, 1968). The results of this test are reported only if the data were found to violate the assumption.

Strategy Analysis

To determine which strategy a subject used, an off-line program analyzed the data from each trial on a response-by-response basis. The program analyzed three major features that permitted the experimenter to identify the strategy: the largest number of sequential responses emitted to each task, the number of simultaneous responses, and the number of switches between tasks.

To determine if two responses were emitted "simultaneously," the times at which the responses were made were compared. If the difference was less than some constant selected by the experimenter, the two responses were classified as simultaneous. If the difference was greater than this constant, it was assumed that the subject switched attention from the first to the second task. The difference between the times at which the responses were made (the onset difference time) then was stored and after all the data for a given trial had been analyzed, the onset differences were summed and divided by the number of switches to obtain an average switching time (it should be noted that this value also contains the processing time for the task).

It was decided arbitrarily that the maximum onset difference for a simultaneous response would be 1/10 of the fastest average response time

recorded to either the ME or the CL task. This value was 33 msec. Previous research (Damos and Wickens, 1980) indicated that there was very little difference in the number of response pairs classified as simultaneous in a given trial when the acceptable response difference time was varied between 33 and 100 msec. That is, generally, if two responses were emitted simultaneously, the onset difference was between 1 and 5 msec. If, on the other hand, the subject had switched between the two tasks, the onset difference was on the order of 400 msec or more. Thus, practically, it was easy to distinguish between a simultaneous response pair and two stimuli which the subject processed and responded to sequentially.

The off-line analysis was conducted on all five Day 1 dual-task trials. The results of previous studies (Damos and Smist, 1980; Damos and Wickens, 1980) indicated that subjects generally do not adopt an identifiable strategy until the fourth or fifth trial. Thus, although all five dual-task trials were analyzed, assignment of the subject to a response strategy group was based primarily on the strategy used during Trial 5. However, if a subject used one strategy on the fourth trial and changed to another strategy on the fifth trial, it was assumed that his "true" strategy was indeterminable and his data were not used in any analyses. Two subjects were found to make such a change. Additionally, if the subject used a "two for one" strategy in which he emitted two response to one task for each response to the other, it was assumed that he did not understand the instructions concerning the equal priority of the two tasks and his data were discarded. Only one subject's data were discarded for this reason.

The subject's response strategy was classified using the following procedure: First, the percentage of between-task switches was calculated by dividing the

number of actual switches by the total number possible. The total possible was equal to 2n-1 where n is the number of responses made to the task responsed to the least. For instance, if the subject made 43 responses to the CL task and 23 to the ME task, the total number of possible switches was 2(23)-1=45. Next, the percentage of simultaneous responses was calculated by dividing the number of simultaneous responses by the total number possible and multiplying by 100%. For the example given above, the total number of possible responses was 23. Finally, the greatest number of sequential responses to either task was noted.

Table 1 shows the distribution of the percentage of simultaneous responses by group. Table 2 gives similar data for the percentage of switches, and the maximum number of sequential responses is given in Table 3. As is evident from these tables, the identification of the subjects' strategies was straightforward; no arbitrary assignments were necessary. Eight subjects used the simultaneous strategy; seven, the alternating strategy; and 22, the massed strategy.

Frequency of Distribution of Response Strategies

A χ^2 frequency test of uniformity was performed comparing the observed proportions of each response strategy with the expected proportions assuming the response strategies were equally distributed in the population. A significant χ^2 was found (χ^2=11.409, p <.01), indicating that the response strategies are not equally likely.

Day 1

Single-task performance. Single- and dual-task performance on Day 1 are shown in Figure 1. The ME data were found to violate the assumption of homogeneity of variance ($F_{max_{21,6}}$ = 115.2273, p <.01). The ME data

TABLE 1

Distribution of the Percentage of Simultaneous Responses by Group

Percentage of Simultaneous Responses	Group: Sim	Alt	Mass
0		7/7*	21/22
1-9			1/22
10-25			
26-40			
41-55			
56-70			
71-85	1/8		
85-99	3/8		
100	4/8		

*The numerator represents the number of subjects whose percentage of simultaneous responses was within the row limits; the denominator is the total number of subjects in the group.

TABLE 2

Distribution of the Percentage of Switches by Group

Percentage of Switches	Group: Sim	Alt	Mass
0	4/8*		
1-9	3/8		10/22
10-25	1/8		6/22
26-40			3/22
41-55			1/22
56-70			1/22
71-85			1/22
85-99		2/7	
100		5/7	

*The numerator represents the number of subjects whose percentage of switches was within the row limits; the denominator is the total number of subjects in the group.

TABLE 3

Maximum Number of Sequential Responses by Group

Maximum Number	Group: Sim	Alt	Mass
1	6/8*	4/7	
2-9	2/8	3/7	6/22
10-15			5/22
16-20			7/22
21-25			1/22
26-30			
31-35			3/22
36-40			
41-45			
46-50			
>50			

*The numerator represents the number of subjects whose maximum number of sequential responses was within the row limits; the denominator is the total number of subjects in a group.

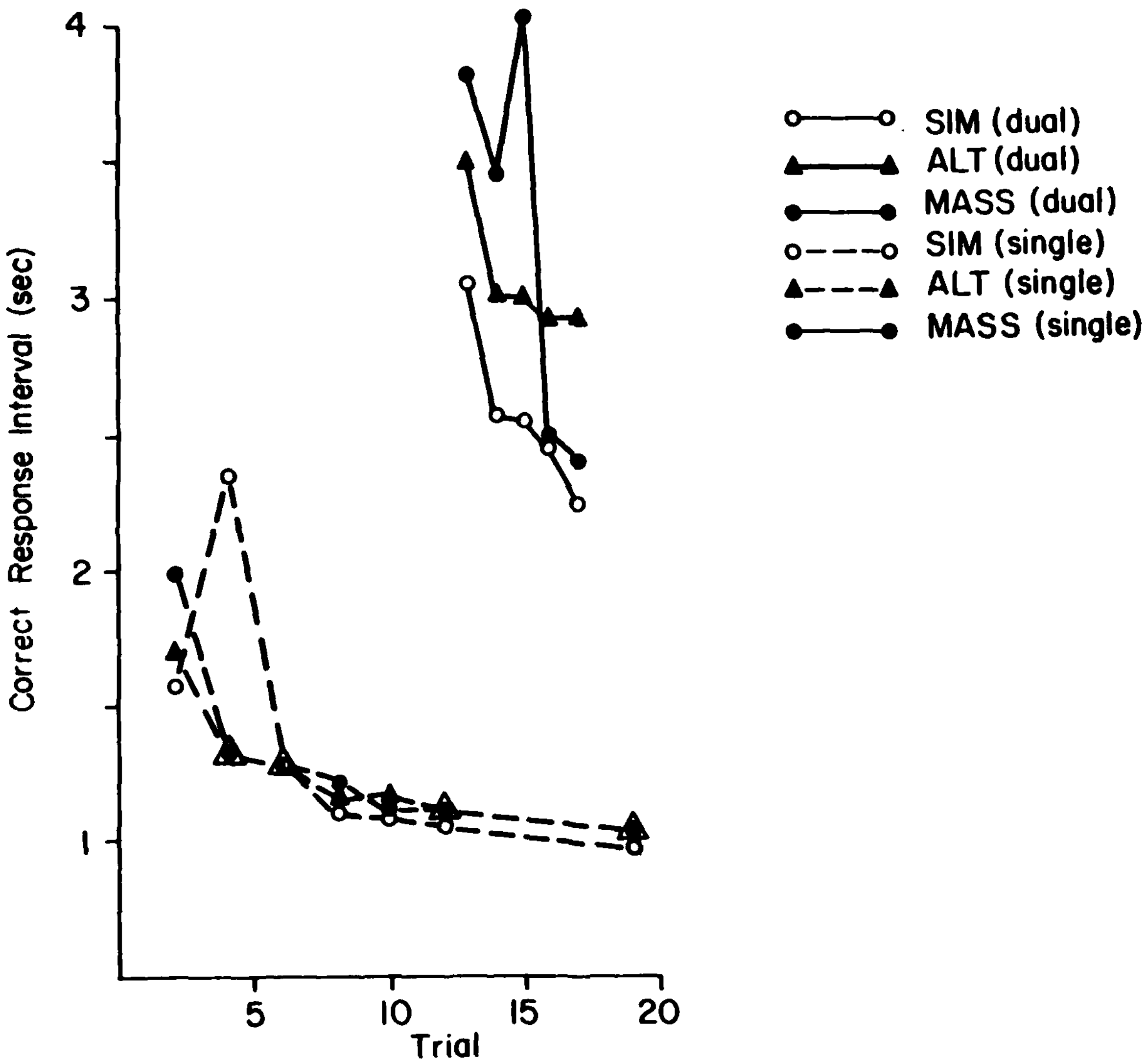

Figure 1. Day 1 single- and dual-task performance by group.

were transformed using $x' = \log(x)$. A two-way (group by trial) repeated measures ANOVA revealed a significant main effect of trial ($F_{6,204}=23.1033$, $p<.001$). The main effect of group and the group by trial interaction were not significant ($p>.05$).

On the first CL trial several subjects either placed their fingers on the wrong keys or interchanged the values of two of the keys. Therefore, a two-way (group by trial) repeated measures ANOVA was conducted on Trials 2 through 7 only. The main effect of trial ($F_{5,170} = 37.2407$, $p<.001$) was significant. Neither the main effect of group nor the group by trial interaction was significant ($p>.05$).

Dual-task performance. Previous research (Damos and Wickens, 1980) indicated that the response strategy used to perform the ME-CL combination was the major determinant of dual-task performance. However, because subjects frequently require several trials before employing an identifiable response strategy, it was assumed that there would be little evidence of between-group differences on Day 1. This hypothesis was examined by performing a three-way (group by trial by task) repeated measures ANOVA on the five Day 1 dual-task trials. The main effect of trial ($F_{4,136} = 10.9817$, $p<.001$) and the task by group interaction were significant ($F_{2,34} = 3.3530$, $p<.05$). To check the hypothesis that the groups did not differ significantly on the first day, between-group differences in performance on just the last dual-task trial were examined using a one-way ANOVA. Again, the effect of group membership was not significant ($p>.05$).

Day 2

Because the strategy used to perform the ME-CL combination is known to have a major effect on dual-task performance (Damos and Smist, 1980; Damos and

Wickens, 1980), it is of no real interest to compare groups using different response strategies. Therefore, all single- and dual-task analyses will be conducted within strategy groups. Single- and dual-task performance for groups using the simultaneous strategy are shown in Figure 2. Comparable data for the alternating response groups are given in Figure 3.

Single-task performance. A two-way (group by trial) repeated measures ANOVA was performed on the ME data for the three groups of subjects using the simultaneous response strategy on Day 2. Both main effects and the interaction were not significant ($p > .05$). An identical analysis conducted on the CL data revealed only a significant main effect of trial ($F_{6,\ 114} = 5.9603$, $p < .001$).

Neither of the comparable analyses performed on the CL and ME data for the two groups using an alternating strategy on Day 2 showed any statistically significant effects.

Dual-task performance. As mentioned previously, it was assumed that if the response strategy is selected at random by the subject, then changing the strategy should disrupt subsequent dual-task performance briefly; and with more practice, the subjects should be able to perform as well with their new strategy as other subjects who adopt it naturally. If, on the other hand, the strategy represents some fundamental differences in information processing, then forcing the subject to change strategies should result in a major disruption in performance. Additionally, the subjects should never perform as well with an adopted strategy as subjects who use that strategy naturally.

To determine if the differences in group performance shown in Figure 2 were significant, a two-way (group by trial) repeated measures simultaneous ANOVA was performed on the dual-task data averaged over tasks for the simultaneous strategy groups.

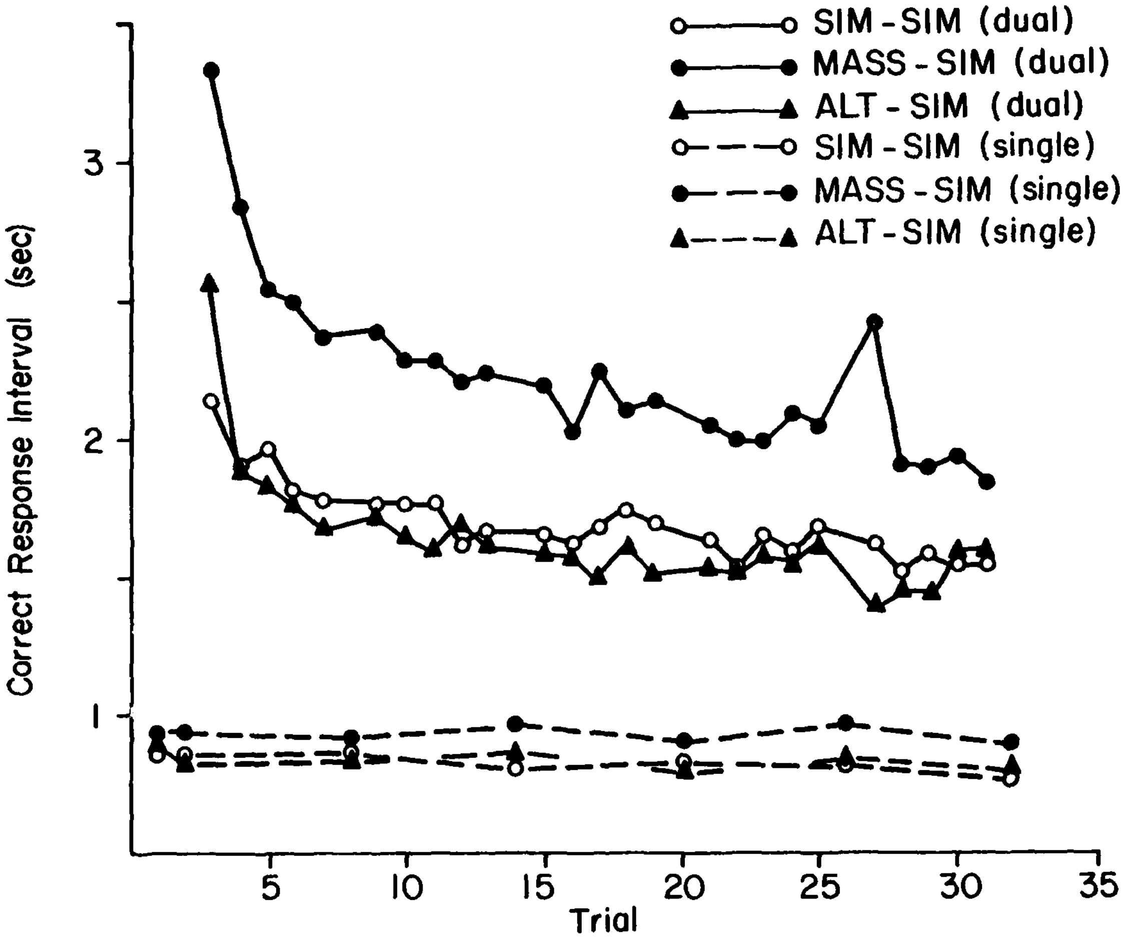

Figure 2. Day 2 single- and dual-task performance for subjects using the simultaneous response strategy.

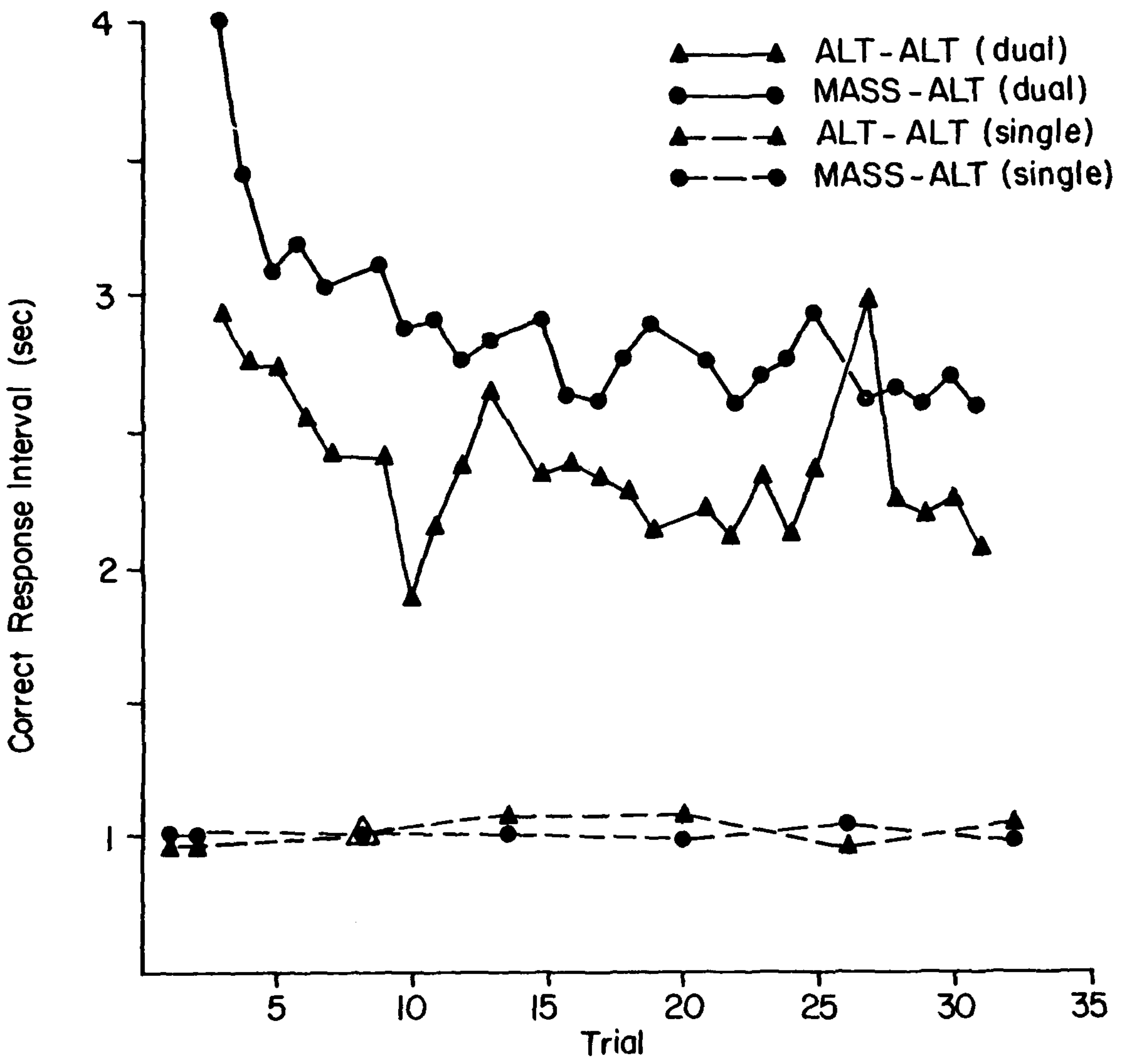

Figure 3. Day 2 single- and dual-task performance for subjects using the alternating response strategy.

Both the main effect of group ($F_{2,19} = 4.5767$, $p < .02$) and trial($F_{25, 456} = 15.4428$, $p < .001$) were reliable. Additionally, the group by trial interaction was significant ($F_{48, 456} = 1.8069$, $p < .001$).

A similar analysis was conducted on the averaged data for the two groups using an alternating strategy. Only the main effect of trial was statistically significant ($F_{24, 312} = 4.7911$, $p < .001$).

Asympotic performance. The ANOVA conducted on the Day 2 dual-task data for the simultaneous response groups indicates a real performance difference between the Mass-Sim Group and the other two groups (see Figure 2). However, this difference could be transitory, indicating only that massed response subjects have difficulty adopting a simultaneous strategy. It does not imply that massed subjects would not perform as well as the simultaneous and alternating subjects given extensive practice.

One way to determine if the performance difference shown in Figure 2 is transitory is to compare the estimated asymptotic performance for each group. This is accomplished by fitting the data using some predetermined equation and estimating the asymptote from the obtained values of one or more parameters. Obviously, the first step in this procedure is to select the equation to be used in fitting the data. For the data from this experiment, there were no theoretical reasons to select one equation over another. Therefore, goodness of fit was the primary criterion.

Initially, the data of a few subjects with very different learning curves were fit using several potentially applicable equations. The equation CRI=a+b/T, where T is the trial number, generally provided the best fit across the various learning curves and subsequently was selected for use.

Two different techniques were used to compare the group asymptotes. First, the average performance for all subjects within each group was obtained on each trial, the average performance data then were fit, and the asymptotes for the three groups compared. Second, each subject's data were fit and a one-way (group) ANOVA was performed on the estimated asymptotes.

The R^2 using the first technique was .953 for the Mass-Sim Group, .959 for the Alt-Sim Group, and .877 for the Sim-Sim Group. The values of "a," the estimated asymptote, were 2.002, 1.504, and 1.620 sec respectively. Although no statistical tests can be performed to compare these three points, it appears that the Alt-Sim and the Sim-Sim Groups approach the same asymptote while the Mass-Sim Group approaches one considerably higher.

After each individual subject's data were fit using the second technique, the R^2 values were examined to determine how well the equation fit the data. The R^2 values for seven of the eight subjects in the Sim-Sim Group ranged from .32 to .74 with a mean of .57. For the eighth subject the inclusion of the linear term did not increase the percent of variance accounted for significantly because his Day 2 data showed almost no evidence of learning. One subject in the Mass-Sim Group used a massed strategy on his third dual-task trial. Performance on this trial was discarded and the data from 24 trials were fit. The R^2 values for the subjects in the Mass-Sim Group ranged from .22 to .90 with a mean of .59. The comparable values for the Alt-Sim Group ranged from .34 to .82 with a mean of .65.

Because some of the R^2 values were unexpectedly low, the data of subjects with R^2 less than .50 were inspected individually. Of the six data sets with R^2 below this value (four from the Mass-Sim Group, one from each of the other two

groups) two apparently had low values because performance was very stable. Thus, the percent variance accounted for by the 1/T term was very small. The low R^2 values for the remaining four subjects, all of whom were in the Mass-Sim Group, were caused by large within-block variations in performance.

To test the appropriateness of the equation Y=a+b/T further, the estimated asymptote "a" was compared to average performance on the last five dual-task trials to determine if it simply was predicting terminal performance. Of the 22 subjects who used a Sim strategy on Day 2, 13 had estimated asymptotes that were an average of 96 msec greater than the average performance during the last dual-task block. It should be noted that the two worst cases of misestimation both occurred for subjects in the Mass-Sim Group (361 and 218 msec) and inflated the average overestimation; without these two subjects the average overestimation was only 56 msec.

The size of the discrepancy between the estimated asymptote and performance on the last five dual-task trials for the two subjects described above caused considerable concern. A one-way ANOVA performed on the estimated asymptotes indicated a statistically significant effect of group ($F_{2, 19} = 4.4666$, $p < .03$). However, the mean estimated asymptote for the Mass-Sim Group was 2.003 sec, which is greater than the average performance on the last four dual-task trials (see Figure 2).

Subsequently, it was decided to eliminate the two Mass-Sim subjects described above (their R^2 were .349 and .379 respectively) and rerun the analysis on 20 subjects. The main effect of group in this analysis just missed statistical significance ($p = .058$). The estimated asymptote for the Mass-Sim Group was 1.851, which is about the performance level of the last four dual-task

trials. The estimates for the Sim-Sim and the Alt-Sim Groups were 1.511 and 1.505 respectively.

Discussion

General Results

Previous research (Damos and Wickens, 1980) indicated that the response strategy used to perform two discrete information processing tasks was the major determinant of dual-task performance. However, the data from this experiment gave no indication whether the strategy was selected at random or somehow reflected some fundamental differences in information processing in multiple-task situations. The purpose of the present experiment was to determine which of these alternatives is the case; if the response strategy reflects consistent individual differences in information processing, then it may be used as a selection tool. If, on the other hand, it is selected at random, then subjects can be trained to use more efficient strategies, thereby improving their performance.

It was assumed that a strategy could be very easily modified if it had not been extensively practiced and was selected at random. If, however, it represented some fundamental differences in information processing, then it was assumed that large disruptions in performance would occur when the subject attempted to use a new strategy and that performance with the new strategy would never be as good as that of subjects who adopted the strategy naturally.

Figure 2 shows that the massed response subjects performed consistently worse on Day 2 than either the alternating or the simultaneous response subjects when they used a simultaneous strategy. The alternating response subjects, however, quickly adjusted to the simultaneous strategy and actually perform slightly better than the subjects who naturally adopt the simultaneous strategy. Figure 3 shows some evidence that the massed response subjects do not perform as well with an alternating strategy as subjects who naturally use the alternating

strategy. However, analysis of these data indicate that the performance of these two groups is not statistically different.

Speed-Accuracy

Before these results can be interpreted, the speed-accuracy data for each group must be examined to determine if the differences evident in Figures 2 and 3 can be attributed to between-group differences in the speed-accuracy trade-off. It should be noted that it is highly unlikely that such a trade-off would account for the observed difference because the CRI reflects both speed and accuracy.

The correct response times (CRT) and the percent errors were averaged over all five trials in each dual-task block. The CRTs and percent errors are shown for each of the component tasks in Table 4. The Mass-Sim Group shows a higher error rate than the Sim-Sim or the Alt-Sim Groups on 60% of the entries and a larger CRT on all of the entries. Thus, the Mass-Sim Group appears to be slower and generally more inaccurate than the other two groups.

Table 4 also indicates that the Alt-Sim Group has a higher error rate on 70% of the trial blocks and a smaller CRT on 80% of the blocks than the Sim-Sim Group. Thus, initially it appears that the Alt-Sim Group may have a different speed-accuracy trade-off than the Sim-Sim Group. A subject-by-subject examination of the data revealed, however, that a very large percent of the errors in the Alt-Sim Group could be attributed to one subject. The entries in Table 4 were recalculated omitting this subject. Under this condition the Alt-Sim Group had smaller CRTs on 80% of the trial blocks and fewer errors on 60% of the trial blocks than the Sim-Sim Group. Thus, omitting one subject, it appears that the Alt-Sim subjects were slightly faster and more accurate than the Sim-Sim subjects.

TABLE 4

Correct Response Time and Percent Error by Trial Block and Group

	Trial Block				
Group	1	2	3	4	5
		Memory Task			
Sim-Sim					
CRT	1.785[a]	1.638	1.571	1.572	1.517
% Error	3.2	1.7	1.4	1.5	1.6
Alt-Sim					
CRT	1.795	1.592	1.498	1.461	1.422
% Error	7.8	2.8	2.4	4.5	3.6
Mass-Sim					
CRT	2.289	2.029	1.910	1.899	1.841
% Error	12.1	6.6	5.8	3.9	3.5
Alt-Alt					
CRT	2.505	2.142	2.111	2.007	2.093
% Error	11.0	5.9	6.9	6.7	8.7
Mass-Alt					
CRT	2.954	2.631	2.490	2.503	2.470
% Error	6.9	5.1	4.6	4.2	3.4
		Classification Task			
Sim-Sim					
CRT	1.856	1.679	1.636	1.583	1.532
% Error	0.9	0.7	1.1	1.0	1.4
Alt-Sim					
CRT	1.846	1.624	1.529	1.511	1.463
% Error	1.9	1.0	0.7	2.1	0.5
Mass-Sim					
CRT	2.437	2.144	2.019	1.965	1.889
% Error	4.9	1.7	0.8	0.6	0.6
Alt-Alt					
CRT	2.395	2.236	2.161	2.085	2.165
% Error	1.1	1.0	0.3	0.9	0.5
Mass-Alt					
CRT	3.135	2.745	2.619	2.623	2.521
% Error	0.9	1.1	0.8	0.7	0.7

[a]CRT scores are given in sec

The Mass-Alt subjects have larger CRTs than the Alt-Alt subjects on 100% of the Table 4 entries but a lower error rate on 70% of the trial blocks. Thus, initially, it appears that these subjects may use a different speed-accuracy trade-off than the Alt-Alt subjects. However, a subject-by-subject examination of the data revealed again that one Alt-Alt subject was responsible for most of the errors in his group. With this subject's data removed, the Alt-Alt subjects still had smaller CRTs on all the Table 4 entries but had lower error rates on 50% of the trial blocks. For the remaining five entries, the maximum difference in error rate between the two groups was 0.9%. Thus, the Alt-Alt subjects are faster and generally more accurate than the Mass-Alt subjects although these differences result in nonsignificantly different CRIs.

Timesharing Skill Comparisons For the Simultaneous Response Groups

If the performance difference between the Mass-Sim Group and the two other simultaneous response groups cannot be attributed to different speed-accuracy trade-offs, it is of some interest to determine why the Mass-Sim Group is slower and more inaccurate than the other two groups. One obvious possibility is that their single-task performance is also poorer than the Sim-Sim and the Alt-Sim Groups. However, analyses of the Day 2 single-task performance showed no significant between-group differences. A second possibility is that this group's timesharing skills were less developed than those of the other two groups. Damos and Wickens (1980) found that a skill in parallel processing was developed by subjects using the simultaneous strategy. Therefore, it is of interest to determine if a comparable skill in parallel processing was learned by these three groups and if there were any between-group differences in the amount of the skill present or in its rate of development.

The development of a skill in parallel information processing was examined by comparing dual-task to single-task CRTs. If the subject processed information in serial but responded to the stimuli simultaneously, the dual-task CRT should be approximately equal to or greater than the sum of the single-task CRTs for the ME and CL tasks. If the dual-task CRT is less than the sum of the single-task CRTs, then some parallel processing may be inferred.

The CRT scores for one subject in the Sim-Sim Group could not be recovered. However, his accuracy was very high. Therefore, estimates of parallel processing were based on his CRI data. The CRT scores of the single-task trials preceding and following a given block were averaged by task and summed to obtain the estimated dual-task CRT for serial processing. A graph of the difference between the dual-task CRT predicted from single-task performance and that obtained is shown in Figure 4. A positive difference indicates that the obtained CRT was larger than the predicted CRT and no parallel processing occurred. A negative score provides evidence of overlapping (parallel) processing. A two-way (group by trial) repeated measures ANOVA indicated a reliable effect of practice ($F_{24, 456} = 9.3850$, $p < .001$).

Thus, it appears that the difference in performance in Figure 2 may be attributed largely to higher error rates for the Mass-Sim subjects relative to the other two groups and their generally slower rate of information processing under dual-task conditions. However, although the main effect of group in the above ANOVA did not reach normally accepted levels of statistical significance ($p = .08$), there is some evidence from Figure 4 that the massed response subjects do not have as much skill in parallel processing as the other subjects.

Asymptotic Performance For the Simultaneous Response Groups

Three different estimates of asymptotic performance were made. The first

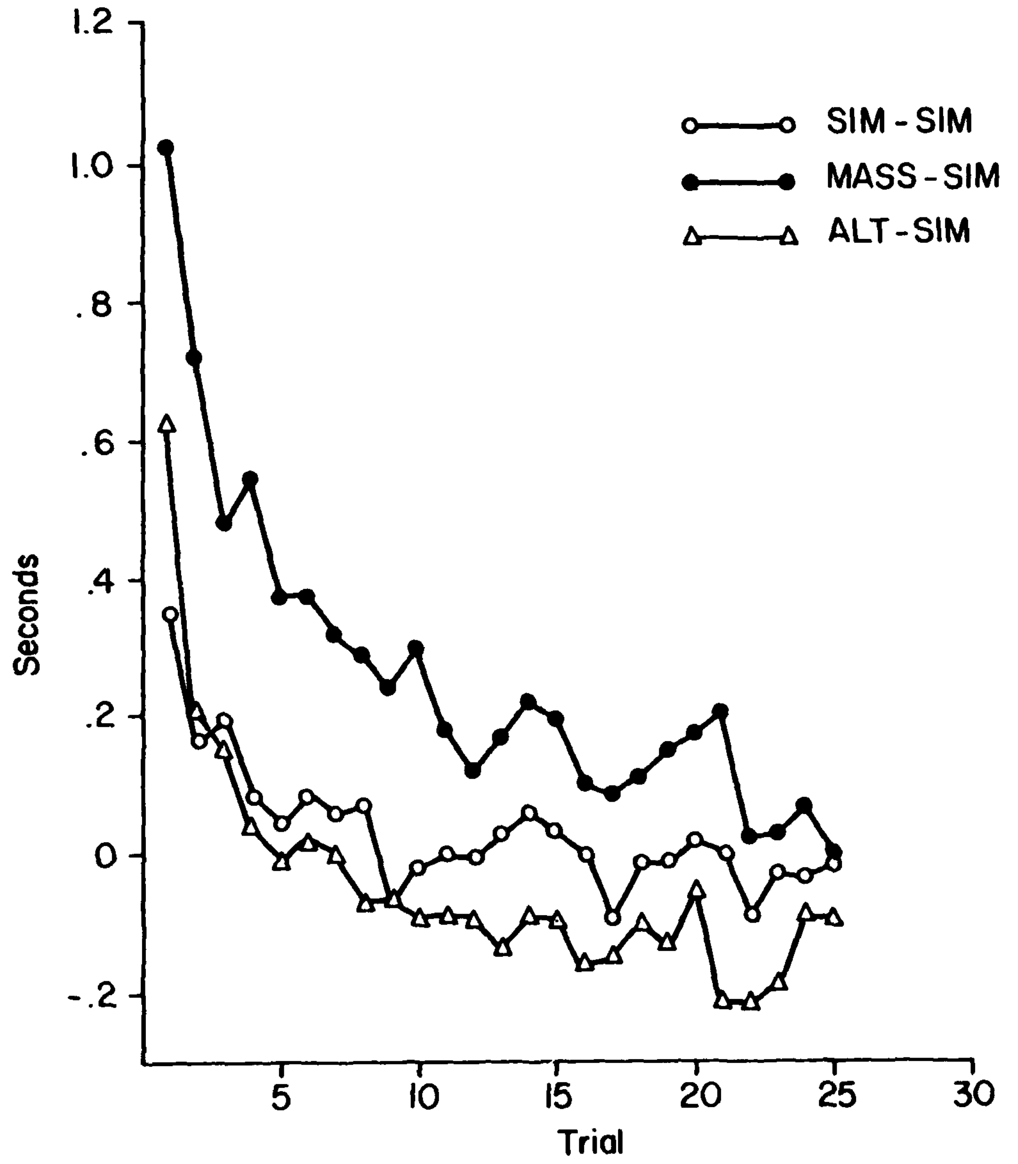

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Figure 4. The difference between estimated and observed dual-task performance for the groups using the simultaneous response strategy on Day 2.

was conducted on the average scores at each trial. The second required each individual subject's data to be fit first and then an ANOVA conducted on the "a" parameter. This technique was done once with all the subjects and once with two Mass-Sim subjects omitted. In all three cases the results were the same: the Sim-Sim and Alt-Sim subjects have the same asymptotic level of performance; the asymptote of the Mass-Sim Group is significantly higher (poorer performance). It should be noted that the two subjects omitted from the third analysis were both from the Mass-Sim Group. This provides further evidence that the massed response subjects have difficulty employing a new response strategy even though it is more efficient than their natural one.

Efficiency of the Alternating and Simultaneous Strategies

Because at least Alt-Sim subjects were able to adopt a simultaneous strategy easily and perform well with it, it is of interest to compare the relative efficiency of these two strategies. Theoretically, the best dual-task performance that could be obtained using the alternating strategy would be equal to the sum of the single-task reaction times (assuming an infinitely fast switching time). In contrast the theoretically best performance that could be expected using the simultaneous strategy would be equal to the slowest single-task reaction time. Thus, with large amounts of practice the asymptotic level of performance for subjects using a simultaneous strategy should be better than for those using an alternating strategy.

This hypothesis was tested by fitting the data for the Alt-Alt and Mass-Alt subjects individually using the equation CRI=a+b/T. Fewer problems were encountered in fitting these two sets of data than the preceding data sets

because performance was more stable: the addition of the b/T term did not increase the percent variance explained for two of the three Alt-Alt subjects and one of the Mass-Alt subjects. Additionally, the inclusion of this term only marginally increased the percent variance explained for two of the other Mass-Alt subjects.

A one-way ANOVA performed on the "a" values for the five response strategy groups indicated a significant effect of group ($F_{4, 32} = 8.5842$, $p < .001$). A planned comparison of the simultaneous versus alternating strategy groups revealed a significant difference between the two sets of asymptotes ($F_{1, 32} = 16.482$, $p < .01$). Thus, the strategy itself may limit dual-task performance.

Timesharing Skills for the Alternating Strategy Groups

One implication of the above finding is that the timesharing skills, i.e. rapid intertask switching, of the Alt-Alt subjects may have been significantly better than those of the Mass-Alt subjects but because switching time accounts for only a fraction of the dual-task reaction time, these differences may not have resulted in statistically significant performance differences. It was decided, therefore, to calculate each subject's switching time on a trial-by-trial basis and compare the two groups on this variable.

To examine switching behavior, it was assumed that the subject processed information from only one task at any given time. The switching time then could be estimated by examining the difference between the single- and dual-task CRTs.

Again, the middle dual-task trial of each Day 2 block was selected for examination. Single-task performance was estimated from the single-task trials preceding and following the block. A mean switching time was obtained by comparing the dual-task CRT averaged over both the ME and CL tasks to the sum

of the average single-task CRTs. One-half the difference between the mean dual-task CRT and the sum of the average CRTs for the CL and ME task is the estimated switching time. The estimated switching times by trial and group are shown in Figure 5. A two-way (group by trial) repeated measures ANOVA revealed that both the main effect of practice and group were statistically significant ($F_{24, 312} = 4.7350$, $p < .001$; $F_{1, 13} = 5.2945$, $p < .05$).

Thus, the Alt-Alt subjects could switch more rapidly between the tasks than the Mass-Alt subjects. The superior timesharing skills of these subjects were not reflected, however, in superior overall dual-task performance because of the limitations imposed on the performance of the alternating strategy itself.

Conclusions

The purpose of this experiment was to determine if the strategy a subject uses is selected at random or reflects some fundamental differences in information processing. The results of this experiment actually support both alternatives. The massed strategy subjects show statistically poorer performance when asked to use a simultaneous strategy than either the Sim-Sim or the Alt-Sim Groups and little, if any, evidence of being able to "catch up" with the other two groups of subjects with extensive practice. Their skill in processing information in parallel appears poorer than that of the other two groups of subjects although the difference is not statistically significant. Their skill in rapid intertask switching is, however, significantly worse than that of the alternating response subjects. In contrast the alternating subjects changed easily to a simultaneous response strategy and had performance that was as good as the control group (Sim-Sim). Additionally, their skills in parallel information processing were as good, if not better, than the controls'.

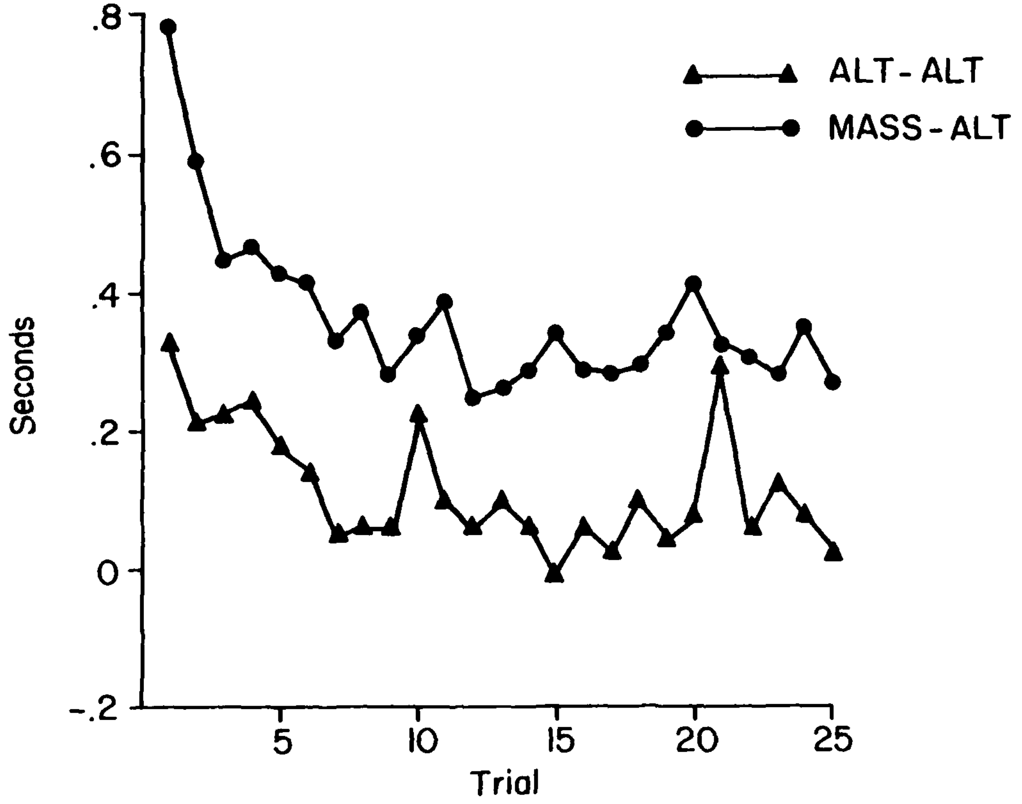

Figure 5. Estimated switching times for the groups using the alternating response strategy on Day 2.

Thus, the multiple-task information processing of a massed response strategy subject appears to be very different from that of a simultaneous or alternating response subject although these two types of subjects do not appear to be different from each other. Although there is no evidence to suggest that the alternating and simultaneous response subjects select their strategies randomly, the ease with which the alternating response subjects changed to a simultaneous strategy suggests that this might be the case.

EXPERIMENT II

Experimental Rationale

The preceding experiment indicates that the response strategy used to perform two discrete information processing tasks reflects some fundamental differences in information processing under high levels of workload. However, it provides no information on the source of these differences.

An examination of the recent literature on individual differences reveals two possible sources of the results. First, the strategy may be related for some reason to one or more cognitive styles, such as field dependence-independence or impulsivity-reflectivity. Because people with different cognitive styles have been shown to perform differently on a variety of tasks, the results of Experiment I could be explained by noting that cognitive styles cannot be easily changed and by demonstrating that the massed response subjects were at one end of a cognitive style dimension while the alternating and simultaneous response strategy subjects were at the other.

A second possible explanation for the results is differences in cerebral lateralization. Damos and Smist (1980) showed that the response strategy used by a given subject was related to his degree of cerebral lateralization. This finding appeared to account for the between-group differences observed across a number of different task combinations, including the ME-CL combination used in the preceding experiment. However, because only 12 subjects participated in the experiment, the results should be viewed as suggestive rather than conclusive.

There is also a third explanation for the results of Experiment I: The observed differences reflect differences in the multi-limb coordination factor described by Fleishman (1958; Fleishman and Hempel, 1956; Fleishman and Ornstein, 1960).

not differences in central processing as supposed. Because almost all of the recent multi-task research has used tasks which are controlled by different limbs, it is possible that all of the recent evidence for timesharing skills and abilities simply reflects a multi-limb coordination factor, not a central information processing ability or skill as assumed.

Experiment II was designed to examine each of the three possible explanations for the results of Experiment I. To test the cognitive styles explanation, the strategy groups were compared on three dimensions of cognitive style: impulsivity-reflectivity (as measured by Kagan's Impulsive-Reflective Test), field dependence-independence (as measured by Witkin's Embedded Figures Test), and extroversion-introversion (as measured by Eysenck's Personality Inventory). Additionally, a test of absorption was included (Telegren's absorption scale) on the grounds that absorption might be negatively related to multiple-task performance.

The cerebral lateralization hypothesis was tested by using the same three tests of hand dominance employed by Damos and Smist (1980): a battery of five psychomotor tests, a questionnaire on hand usage, and a "writing" test developed by Levy (Levy and Reid, 1978). To determine if multi-limb coordination is the factor responsible for individual differences in multiple-task performance, the Two-Hand Coordination Test was included in the experiment. This is one of the tests which loads heavily on the multi-limb coordination factor (Fleishman, 1958; Fleishman and Hempel, 1956) and appears to require little central processing. Of course, because response strategies are not perfectly correlated with multiple-task performance, the relation between each of the tests described above and multiple-task performance also will be examined.

A brief biography also was included in Experiment II to determine if the subjects had participated in sports, such as diving, or activities, such as motor cycle driving, which had been found to predict success in pilot training. If such activities were related to the response strategy used in multiple-task situations, then the response strategy might be useful in predicting pilot performance.

In Experiment I three subjects were eliminated because they used a "mixed" strategy that could not be clearly identified. Several subjects in preceding experiments had used these mixed strategies (Damos and Smist, 1980; Damos and Wickens, 1980) but they always had been grouped with the massed strategy subjects. Reflection indicates, however, that such grouping might not be appropriate because the mixed strategy subjects may be those whose timesharing skills are so well developed that they can experiment with different strategies. Therefore, another purpose of this experiment was to determine if subjects who employ a mixed strategy should be treated separately from those employing one of the identifiable strategies or if they should be grouped with the massed strategy subjects as assumed previously.

Method

Tasks

ME, CL. The same ME and CL tasks used in Experiment 1 were used in this experiment and the same dependent measures were recorded.

Tracking (TR). Two identical one-dimensional compensatory tracking tasks each required the subject to keep a moving circle centered in a horizontal track by making appropriate left-right manipulations of a control stick. One task was controlled by each hand. The inputs to the two displays consisted of the sum of sine waves of .02, .03, .07, .13, .23, .41, .83, 1.51, and 3.07 Hz. The inputs to the two displays were independent. The control systems had mixed first- and second-order dynamics with weightings of 0.15 and 0.85 respectively.

Average absolute errors were calculated for each task and presented to the subject at the end of each trial, one indication for single-task trials and two for dual-task trials. Additionally, the positions of the control stick and the error cursor were recorded every 100 msec for later off-line analysis. The tracking tasks that were controlled by the left and right hands were appropriately offset to the left and right of the display center. The visual angles subtended by the display were 3.41° by 0.29°.

Biography. The biography consisted of a number of short questions concerning the amount of time the subject devoted to playing a musical instrument, athletics, and riding a motor cycle (see Appendix C).

Eysenck Personality Inventory. Form A-I of the inventory (Eysenck, 1963) was used. The subjects were required to respond "yes" or "no" to 57 items, 24 of which measured introversion-extroversion. The dependent measure was the number of extrovert answers.

Tellegen absorption scale. Thirty-four items used to define the absorption dimension of Tellegen's Differential Questionnaire were interspersed with 36 filler items selected at random from the other scales of the questionnaire. The subjects marked each question "true" or "false" according to whether it described them. The dependent measure was the number of "true" answers.

Kagan's Impulsive-Reflective Test. The 12-item adolescent/adult version (Kagan, 1969) of Kagan's Impulsive-Reflective Test required the subject to match a standard drawing to one of six or eight similar pictures. Only one of the alternatives was identical to the standard; the others varied in some small detail. Two dependent measures were recorded for each standard: time to the first response and the number of errors to correct response. Each of these two scores was summed over the 12 items to give a total time to first response score and a total number of errors score, which were used in all subsequent analyses.

Witkin's Embedded Figures Test. This test required the subject to find a simple figure embedded in a more complex figure. Form A (Witkin, 1971), the version used in this experiment, consisted of 12 colored figures and eight simple line drawings. The sum of the time to correct solution for each stimulus was used as the dependent measure.

Two-Hand Coordination Test. For this test the subject attempted to keep a pointer in contact with a moving target. The target was mounted on a disc which rotated slowly clockwise. Additionally, the target moved irregularly in a curved slot in the disc. The subject moved the pointer by turning two cranks, one with the left hand and the other with the right. One crank controlled the vertical position of the cursor; the other, the horizontal position of the cursor. The total time on target was recorded for each trial and served as the dependent variable

Laterality battery. Five motor tests and a questionnaire were given to assess the subject's cerebral lateralization through hand dominance. The first laterality test required the subject to screw six nuts onto a bolt as quickly as possible. The second required the subject to press a key as many times as possible in a 30-sec period. The third was a test of hand strength; the subject squeezed a hand dynamometer as hard as possible. The fourth consisted of the single-hand subtest of the Purdue Pegboard Test (Lafayette Instrument Company, 1971). The fifth test required the subject to balance a 94 cm dowl on his index finger as long as possible.

Before each test the subject was asked to judge which hand would have the best score and begin with that hand. The subject performed each task four times alternating between hands. For each task a score of +1 was recorded if the subject began with his right hand, a score of -1 if he began with his left.

The questionnaire asked about hand usage for a number of everyday activities (see Appendix D). A score of +1 was given for each "right hand" answer, a score of "0" for each "both hands" answer, and a score of -1 for each "left hand" answer. The sum of the scores, which could range between ± 15, was the dependent variable.

Apparatus

ME, CL. The apparatus used for the ME and CL tasks was identical to that used in Experiment I.

TR. The TR task was displayed on the same CRT used for the ME and CL tasks. The forcing function was recorded on a cassette tape and was played on a Phillips Minilog 4 Data Recorder. The output of the recorder was fed through filters that

were implemented on two EAI TR-20 analog computers to provide the desired power spectrum of the forcing function. The control system dynamics also were programmed on one of the EAI TR-20 computers. Subjects tracked the function using a pair of Measurement Systems Incorporated Model 541 Two-Axis Gimbal Joysticks. Both sticks were modified to permit movement in the left-right dimension only.

Subjects

Right-handed males between the ages of 18 and 35 were recruited through advertisements placed in various university buildings. Only native English speakers who had not received any flight training were allowed to participate. Before the subject began the experiment, his vision was tested. No subject was allowed to participate with vision less than 14/18. Additionally, Levy's test for inverted versus normal writing position (Levy and Reid, 1978) was given as a check for normal cerebral lateralization. None of the subjects used the inverted position. Because of equipment malfunctions only 35 of the 41 subjects who began the experiment completed it.

Design

A completely within-subject design was used.

Procedure

Each subject was sent a copy of the Tellegen absorption scale, Form A of the Eysenck Personality Inventory, the biography, and the questionnaire portion of the laterality battery. The subject completed each form at home and brought the completed forms to the first day of the experiment.

On any given day the first subject to begin the experiment on that day was assigned to Experimenter A, the second to B, the third to A, etc. On the following day the order was reversed so that the first new subject was assigned to Experimenter B, the second to A, etc. One experimenter tested the subject on both Days 1 and 2. After the subject had been assigned to an experimenter, he read a briefing sheet and completed an informed consent form. He then was given a binocular near-vision acuity test, the writing test, and the Two-Hand Coordination Test, which consisted of eight 1-min trials with a 15-sec break between trials.

Next, he was taken to the experimental room and heard taped instructions for single-task tracking (see Appendix E). The subject performed ten trials of single-task tracking, alternating between the two hands and beginning with the right hand. Instructions for dual-task tracking then were played and the subject performed two blocks of five dual-task trials (see Appendix E). Each block was followed by two single-task trials, one on each hand and always beginning with the right hand.

After a 5-min break the subject returned to the testing room and was given Kagen's Impulsive-Reflective Test followed by Witkin's Embedded Figures Test. He then moved to the experimental room and heard taped instructions describing the ME task (see Appendix A). The subject performed one trial of the ME task and then heard a second set of instructions describing the CL task (see Appendix A). The subject subsequently performed 11 single-task trials, alternating between tasks. After a 2-min break the subject heard taped instructions describing the ME-CL combination (see Appendix A). The subject performed five dual-task trials, followed by two single-task trials, one for each task. The entire session lasted approximately 3 hours.

Day 2. The subject first was given the five motor tests of the laterality battery and subsequently was taken to the experimental room and reminded of the tracking instructions. He then performed four single-task tracking trials beginning with the right hand and alternating between hands. After completing the initial single-task trials, he performed three blocks of five dual-task trials. Between each block he again performed one single-task trial with each hand, always beginning with the right hand. A short break of approximately 2 min was given at the beginning of the second dual block.

After the subject completed the Day 2 tracking, he was given a 5-min break. He then performed two single-task trials on each of the ME and CL tasks beginning with the ME task and alternating between hands. Subsequently, he performed three five-trial dual-task blocks. Each block was followed by one single-task trial on each task.

After the subject had completed the last single-task trial, he received a debriefing sheet and was paid. The entire testing session on Day 2 lasted approximately 2.5 hours.

Results

Strategy Analysis

The fifth dual-task trial on Day 1 was examined to classify the subject's response strategy using the same technique as in Experiment I. All dual-task data were examined to determine if any subject switched strategy between Days 1 and 2. None were found to do so.

Table 5 shows the distribution of the percentage of simultaneous responses by group. Tables 6 and 7 give similar data for the percentage of switches and the maximum number of serial responses. As is evident from these tables, the subjects who used the simultaneous and alternating response strategies can be identified easily by the percentage of switches and simultaneous responses emitted and the small maximum number of sequential responses (typically one or two). The massed response subjects can be identified by the fact that they emit no simultaneous responses, make fewer switches than the alternating response subjects, and, consequently, have a larger maximum number of sequential responses.

Some comment is necessary about the "mixed" classification. Many of these subjects switched strategies between trials, but on any given trial the strategy usually could be classified as massed, alternating, or simultaneous. Therefore, a response strategy was classified as "mixed" on the basis of performance across a number of dual-task trials.

Intercorrelation of the Cognitive Styles Tests, Laterality Battery, and the Two-Hand Coordination Test

The intercorrelations between the four tests of cognitive style, the total time on target for the Two-Hand Coordination Test, and the laterality battery are given in Table 8.

TABLE 5

Distribution of the Percentage of Simultaneous Responses by Group

	Group			
Percentage of Simultaneous Responses	Sim	Alt	Mass	Mixed
0		2/2*	16/16	5/7
1-9				1/7
10-25	1/10			
26-40				
41-55				
56-70				
71-85				
85-99	4/10			
100	5/10			1/7

*The numerator represents the number of subjects whose percentage of simultaneous responses was within the row limits; the denominator is the total number of subjects in the group.

TABLE 6

Distribution of the Percentage of Switches by Group

Percentage of Switches	Group			
	Sim	Alt	Mass	Mixed
0	6/10*			1/7
1-9	3/10		7/16	2/7
10-25	1/10		5/16	2/7
26-40			2/16	1/7
41-55				
56-70				
71-85		1/2		
85-99			2/16	1/7
100		1/2		

*The numerator represents the number of subjects whose percentage of switches was within the row limits; the denominator is the total number of subjects in the group.

TABLE 7

Maximum Number of Sequential Responses by Group

	Group			
Maximum Number	Sim	Alt	Mass	Mixed
1	9/10*	1/2		1/7
2-9		1/2	5/16	2/7
10-15			3/16	1/7
16-20	1/10		3/16	1/7
21-25				1/7
26-30			1/16	
31-35			1/16	
36-40				1/7
41-45				
46-50				
50			3/16	

*The numerator represents the number of subjects whose maximum number of sequential responses was within the row limits; the denominator is the total number of subjects in a group.

TABLE 8

Intercorrelations of Cognitive Styles Tests, Laterality Tests, and Two-Hand Coordination Test

Test	2	3	4	5	6	7	8
1. Impulsive-Reflective (Time)	-.727**	.048	-.139	-.087	-.095	-.028	.110
2. Impulsive-Reflective (Error)		.057	.223	-.015	.001	.143	-.085
3. Embedded Figures			-.297	-.113	.111	.256	-.381*
4. Extroversion				.397*	.037	-.081	.257
5. Absorption					-.236	.323	-.196
6. Laterality Test (Psychomotor)						.166	-.307
7. Laterality Test (Questionnaire)							.041
8. Two-Hand Coordination							

*$p < .05$
**$p < .01$

Between-Group Comparisons on the Cognitive Styles Tests, Laterality Battery, and the Two-Hand Coordination Test

One-way ANOVAs were performed on the four tests of cognitive style and the two laterality tests to determine if there were any significant between-response group differences on these tests. None was found ($p > .05$).

A two-way (group by trial) repeated measures ANOVA was performed on the time-on-target scores for the Two-Hand Coordination Test (see Figure 6). Both the main effect of trial ($F_{7, 217} = 12.684$, $p < .001$) and group was significant ($F_{3, 31} = 4.971$, $p < .01$). The interaction was not significant ($p > .05$).

Biography

Preliminary analyses indicated that many of the subjects never participated in any of the activities addressed in the questionnaire. Additionally, there were no obvious between-group differences in either the number of subjects participating in the various activities or the amount of time devoted to the activities. For these two reasons no further analyses were performed on the biography.

Between-Group Comparisons of Dual-Task Performance

Previous research (Damos and Smist, 1980; Damos and Wickens, 1980) demonstrated a relation between the response strategy used on the ME-CL combination and performance on several different combinations. It was of some interest, therefore, to see if the same relations were replicated in this experiment by examining between-group differences on the two task combinations. Performance by groups on both task combinations is shown in Figures 7-9. To maximize the probability of finding any differences that may occur, only data which have reached

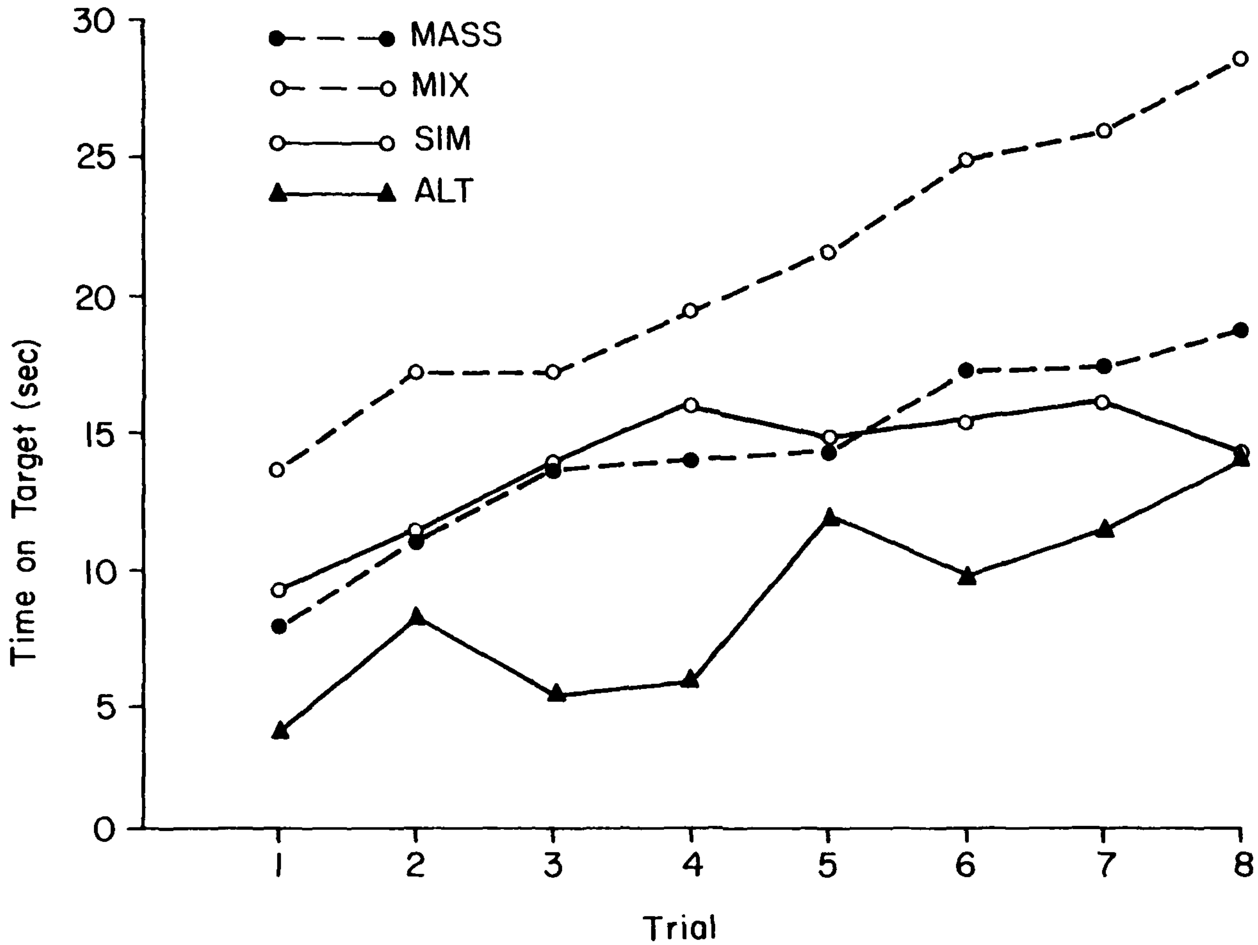

Figure 6. Time-on-target scores by group and trial.

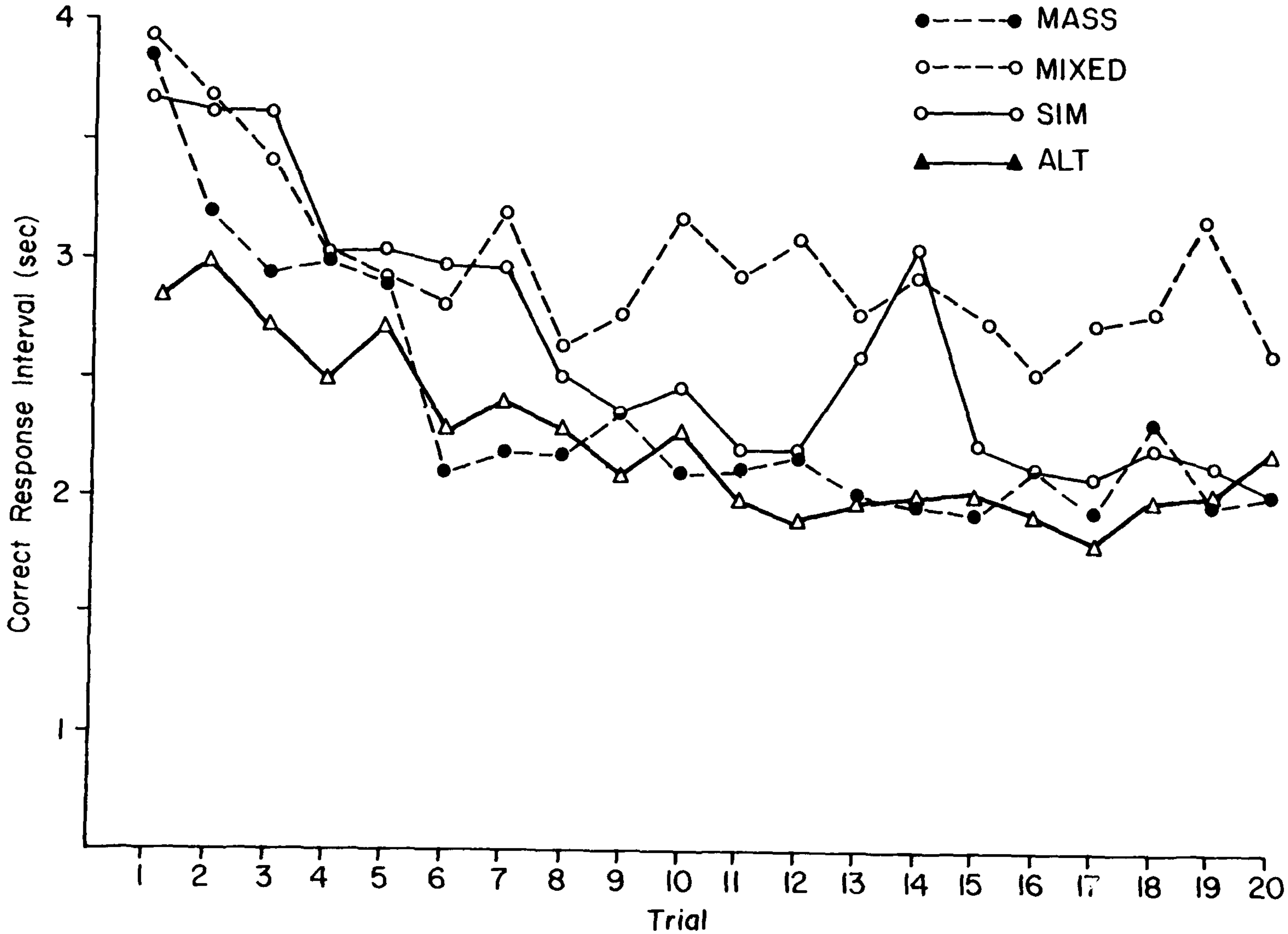

Figure 7. Dual-task CL performance on Days 1 and 2 by group.

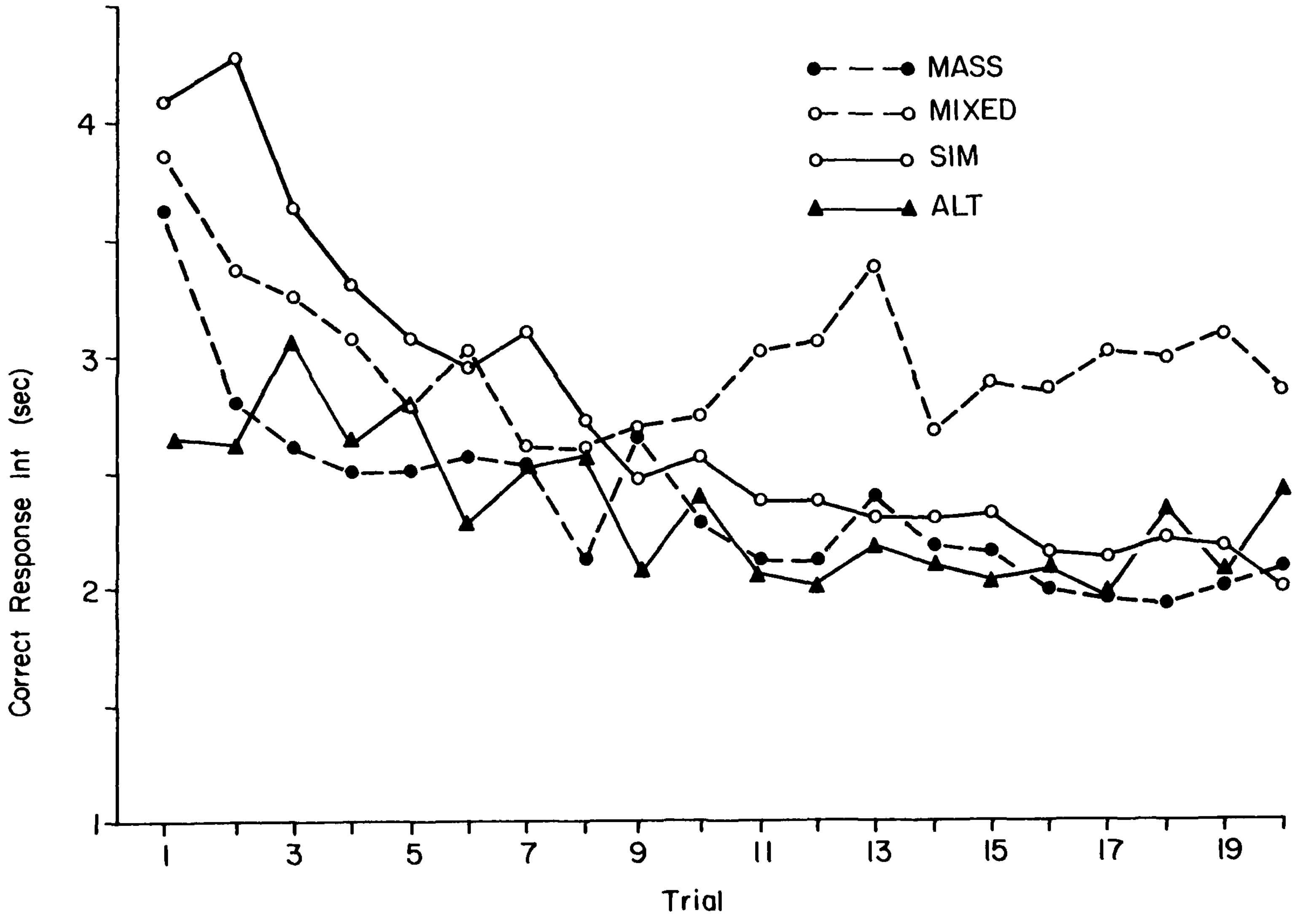

Figure 8. Dual-task ME performance on Days 1 and 2 by group.

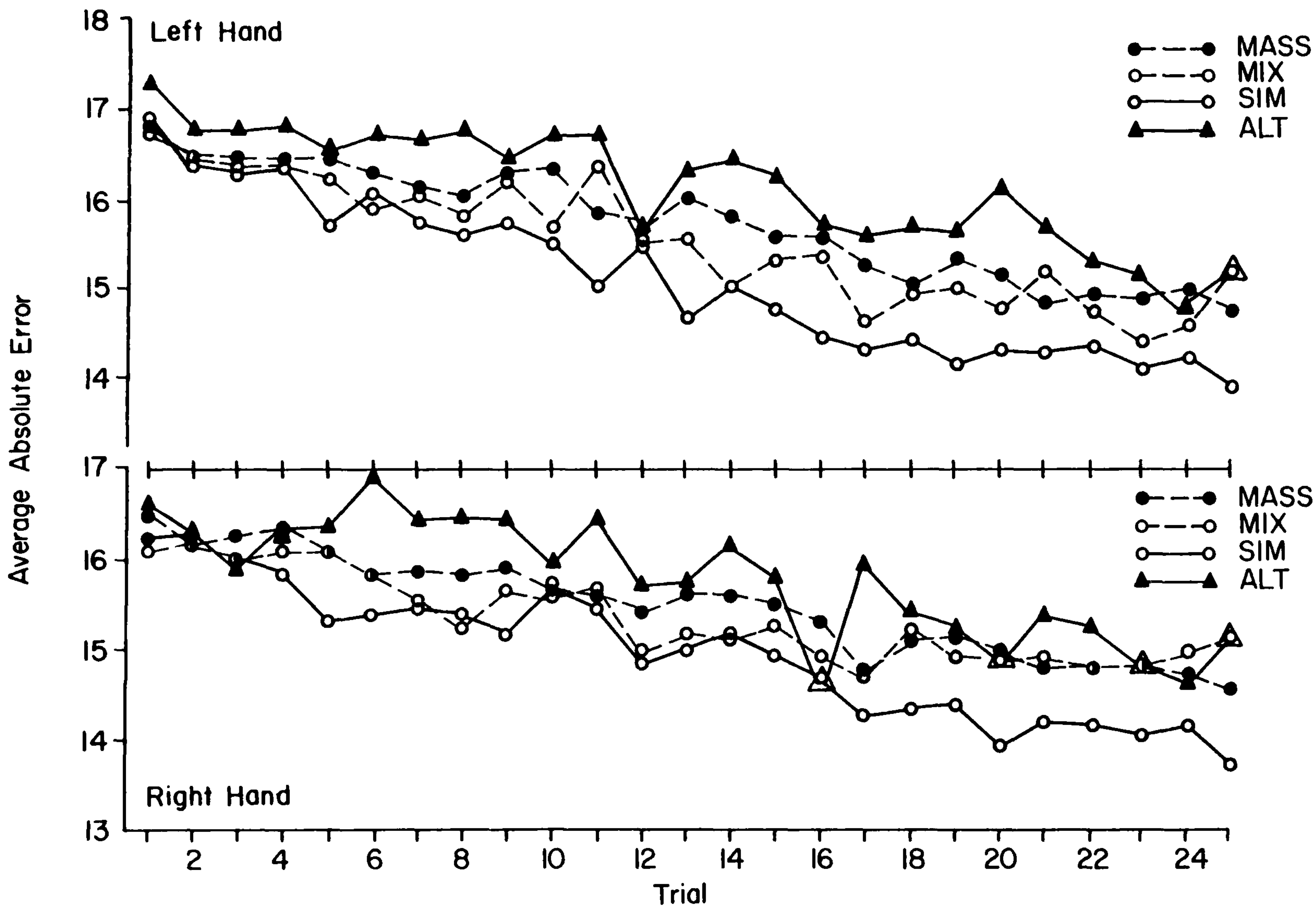

Figure 9. Dual task TR performance on Days 1 and 2 by group.

"differential stability" should be analyzed. This term implies that the rank order of the subjects is constant within experimental error from trial to trial although some overall group learning still may be occurring (Jones, 1979). Additionally, dual-task performance should be corrected for individual differences in single-task performance to obtain a better estimate of multiple-task performance.

Single-task performance. Single-task data were examined for any evidence of between-group differences. Before any ANOVAs were performed, all four data sets (left-hand TR, right-hand TR, ME, and CL) had to be transformed using $X' = \log X$ to avoid violating the assumption of homogeniety of variance. Additionally, the first single-task ME trial was discarded because a number of subjects did not understand the instructions.

None of the four two-way repeated measures ANOVAs revealed a significant main effect of group ($p > .05$) or a significant group by trial interaction ($p > .05$). All four did show a main effect of trial ($F_{10,\ 310} = 7.5442$ for the transformed ME data; $F_{11,\ 341} = 15.6181$ for the transformed left-hand TR; $F_{11,\ 341} = 28.4813$ for the transformed right-hand TR; and $F_{11,\ 341} = 64.9106$ for the transformed CL data). In all cases $p < .001$.

Differential stability tests. The data were examined using a technique based on Lawley's χ^2 suggested by Bittner (1979). The rationale for the test is that the intertrial correlation matrix of a task which has not obtained differential stability most probably will have simplex structure (correlations decreasing left to right and increasing top to bottom). Lawley's χ^2 tests the assumption that all intertrial correlations are equal.

To use this technique, the experimenter first estimates visually where the simplex structure of the intertrial correlation matrix ceases, say after

row j, and then performs the χ^2 test on the submatrix formed by rows j through n and columns j through n. If the χ^2 is not significant, implying that performance after the j^{th} trial is stable, then the (j-1) through n submatrix is examined. If this also is not significant, then the (j-2) through n submatrix is examined etc. until the χ^2 test becomes significant, say after including row (j-i). Thus, performance is stable on the $(j-i+1)^{th}$ trial and unstable preceding that point.

Before conducting stability tests on the dual-task TR scores, a two-way (hand by trial) repeated measures ANOVA was performed to determine if there was a reliable performance difference between the left and right hands. The analysis revealed a significant effect of trials ($F_{24, 816} = 31.4352$, $p < 001$) and a significant effect of hand ($F_{1, 34} = 29.3278$, $p < .001$). Thus, tracking scores could not be averaged over hands as in previous studies (Damos and Wickens, 1980; Damos and Smist, 1980).

Stability tests performed on the dual-task tracking scores indicated that performance stabilized between the 15th and 16th trials for both hands. Similar tests performed on the dual-task ME and CL scores showed that performance stabilized between the 17th and 18th trials for both tasks.

Between-group analyses. Because only three dual-task trials of the ME-CL combination were stable, there was little reason to perform two-way analyses. Therefore, a one-way ANOVA was conducted on the sum of the stabilized ME scores corrected for individual differences in single-task performance and an identical analysis on the corresponding CL scores. Individual differences in single-task performance on each task were taken into account by averaging the scores on the single-task trials preceding and following each dual-task block with stabilized

trials and subtracting this value from the dual-task scores of the same task on each stabilized trial within that block. Only the analysis on the corrected ME scores showed a significant main effect of group ($F_{3, 31} = 5.2129$, $p < .005$) with the mixed response strategy subjects having the worst performance.

The stabilized left-hand and right-hand TR scores were corrected for individual differences in single-task performance using the same technique described above. Because the significant between-group difference on the Two-Hand Coordination Test may indicate significant differences in multi-limb coordination, two-way analyses of covariance (group by trial) were performed on the stabilized corrected left-hand and right-hand scores with the total time on target as the covariate. Only the main effect of trials for the left-hand TR was significant ($F_{9, 279} = 2.9252$, $p < .002$).

Dual-Task Performance and Scores On the Cognitive Styles Tests, Laterality Battery, and the Two-Hand Coordination Test

To examine the relation between dual-task performance on each combination and performance on each of the other tests, the stabilized corrected difference scores on each task were summed to obtain one measure of performance which could be correlated with each of the other tests. Only the extroversion scale of the Eysenck Personality Inventory correlated significantly ($p < .05$) with any of the dual-task performance measures. It correlated -.425 with the stabilized corrected right-hand TR scores and -.446 with the corresponding left-hand TR scores.

Discussion

Although some caution must be used in interpreting the results because of the small number of subjects who used the alternating strategy, the data indicate that the response strategy used to perform the ME-CL task combination is not related to cognitive styles, cerebral lateralization (as in Damos and Smist, 1980), the activities tapped by the biography, or dual-task tracking performance. Although there were significant differences between strategy groups on the Two-Hand Coordination Test, performance on this test is not related to dual-task TR, implying that performance on dual-task TR is determined primarily by information processing factors rather than limb coordination. All correlations between the sum of the stabilized corrected dual-task scores of each component task and performance on all other tests used in this experiment were not significant except for the two between the extroversion scale of Eysenck's Personality Inventory and left- and right-hand TR. These correlations replicated the results of Corcoran (1972) who examined TR performance and the extroversion-introversion dimension of personality.

One of the main purposes of this experiment was to determine if the mixed response strategy is a type of massed strategy as has been assumed previously (Damos and Smist, 1980; Damos and Wickens, 1980) or if it represents a distinct strategy that should be treated separately. An examination of Figures 7 and 8 indicates that subjects using a mixed response strategy have much worse performance on the ME-CL combination late in practice than subjects in any of the other groups. This, however, was to be anticipated from the nature of the strategy itself. An examination of dual-task TR performance (see Figure 9) indicates the mixed group appears to be most similar to the massed group strategy both in terms of the shape of the learning curve and the performance scores Figure 6,

performance on the Two-Hand Coordination Test, also reveals that the mixed strategy group is most like the massed group (both in terms of the shape of the learning curve and the performance scores on a given trial). Thus, it appears that subjects who employ the mixed response strategy may be grouped with those employing a massed strategy in future studies.

One final comment is in order concerning the relation among the various tests of cognitive style, laterality, and motor coordination used in this experiment. Generally, it has been assumed that cognitive styles are not highly intercorrelated (Ausburn, 1979). Table 8 appears to bear out this assumption. The two intertest correlations which are significant, therefore, are of some interest. The correlation between the Embedded Figures Test and the Two-Hand Coordination Test might be explained by noting that the Two-Hand Coordination Test may require the subject to decompose the movement of the target into a horizontal and a vertical component. Thus, it may require an analysis of a visual path similar to the analysis required to find an embedded figure. The correlation between absorption and extroversion replicates other work by Tellegen which has found correlations of approximately the same magnitude (Tellegen, personal communication, 1980).

EXPERIMENT III

Experimental Rationale

Because Experiment II showed no evidence that response styles are related to any cognitive functions or to limb coordination, the between-group differences found in Experiment I must be related to some other aspect of information processing. One possible explanation rests on the multi-pools model of attention proposed by Kantowitz and Knight (1976), Navon and Gohper (1979), and Wickens (1980). This model hypothesizes that human information processing capacity is subdivided into a number of distinct "pools" rather than residing in one large reservoir as proposed by Kahneman (1974). A major assumption of this model is that processing resources cannot be shared between pools. Thus, if two tasks do not require any common pools, then they will show no dual-task interference. If one or more pools must be used by both tasks, a dual-task decrement and performance trade-offs will be evident to the extent that the processing demands exceed the available capacity.

The results of Experiment I may be explained by assuming that the subjects who used the massed response strategy have less capacity in one or more of the pools than subjects who use other strategies. Thus, the dual-task reaction time is greater than that of the other response strategy groups although their single-task performances are very similar.

To test this assumption, subjects were asked to perform a choice reaction time task at 1, 2, and 3 bits of information under single- and dual-task conditions. A choice reaction time task was selected because the data could be analyzed using the Hick-Hyman Law (Hick, 1952; Hyman, 1953) and estimates of

some of the processing stages obtained by examining the slope (central processing stages) and intercept (encoding and motor response stages) of the regression equation.

The assumption that subjects who use different response strategies have different amounts of processing capacity in certain pools can be tested only to the extent that the paired task requires the same processing pools. A variation of the classification task used in Experiments I and II was selected for this experiment (this task will be referred to as CL(2)). Like the choice reaction time task this task does not require short-term memory, involves no transformations, and needs only a simple discrete response.

Pretest data indicated that under low levels of multiple-task processing load, a very large percentage of subjects adopted a simultaneous response strategy. However, as the load increased, fewer and fewer subjects could maintain this strategy and changed to an alternating or massed strategy. Consequently, there was some concern that the subjects might not use their true response strategy at the 1- and possibly the 2-bit level of the choice reaction time task. To determine the subject's "true" strategy, therefore, all subjects were tested initially on the same combination used in Experiment I before they performed the choice reaction time task with the modified CL task.

Method

Tasks

ME, CL. The same ME and CL tasks used in Experiments I and II were used in this experiment and the same dependent variables were recorded.

CL(2). In this task pairs of randomly selected geometric figures were presented to the subject. Figures shown included rectangles, squares and triangles. The figures could vary on two dimensions: shape and height. The subject determined the number of dimensions a pair of figures had in common and responded by pushing one of three corresponding keys on the left-hand keyboard. The keys were numbered from left to right beginning with "0." As soon as a response was made, the pair was erased from the screen and a new pair presented.

Following each trial, subjects were shown the CRI and correct response percentage statistics. The visual angle subtended by the display was 0.72° by 0.36°. The height ratio of small to large stimuli was approximately 0.8.

Choice reaction time (CR). For this task randomly selected digits were presented sequentially to the subject. Task difficulty was manipulated by varying the number of stimulus alternatives to give 1-, 2-, and 3-bits of information. In the 1-bit condition (two alternatives) the digits one and two were used. In the 2-bit condition (four alternatives) the digits one through four were used; in the 3-bit condition (eight alternatives) the digits one through eight were used. The subject responded to the digit being displayed by pressing the appropriate key on the right-hand keyboard. Two rows of keys were used which were numbered from left to right. The lower row contained the keys one through four; the upper row, five through eight. As soon as a response was made, the stimulus was erased and a new one presented.

The CRI and percentage of correct responses were calculated and presented to the subject following each trial. Under single-task conditions the display subtended a visual angle of 0.72° by 0.22°. Under dual-task conditions, stimuli for the CL(2) task were presented on the left side of the screen and digits for the CRT task were presented on the right side of the screen. The visual angle subtended by the dual-task display was 1.43° by 0.50°.

Apparatus

The same apparatus used in Experiment I was used in this experiment.

Design

A four factor mixed model repeated measures design was used. The four factors were group (simultaneous, alternating, or massed response strategy), trial, processing load (single- or dual-task), and stimulus information level (1, 2, or 3 bits) of the CR task. The order in which the information levels of the CR task were presented was randomized between subjects.

Subjects

Subjects were right-handed native English speaking males between the ages of 18 and 35 who responded to advertisements placed in campus buildings. All subjects were required to have no experience in piloting an aircraft, good vision, and no significant physical handicaps. Thirty-three subjects began the experiment. Five subjects were excused as a result of equipment difficulties and two subjects dropped out prior to completion of the third session. Subjects were paid $4 per hour.

Procedure

Day 1. Before taking part in the experiment, all subjects were given a vision examination consisting of a binocular near-vision acuity test. The test was terminated when a subject incorrectly identified two consecutive stimuli or correctly identified all stimuli up to and including the 20/20 cutoff point. Any subject who failed the vision test was not allowed to participate in the experiment.

The Purdue Pegboard Test was administered to obtain a basic measure of dexterity and coordination for each subject. Subjects received a right- and then a left-hand trial, followed by a trial in which both hands were used simultaneously. Each trial lasted 30 sec.

The subjects then listened to taped instructions for the ME task (see Appendix A) and performed one single-task trial. Next, they were presented with taped instructions for the CL task (see Appendix A) and subsequently performed one single-task CL trial followed by eight additional single-task trials, alternating between the ME and CL tasks on each successive trial.

After the single-task practice the subjects heard taped instructions for the dual-task combination (see Appendix A). They then performed five dual-task trials All trials were 1 min long followed by a 1-min rest pause. Feedback concerning performance on the preceding trial was presented during the rest pauses. A 2-min break was given following the last dual-task trial.

Next, subjects listened to taped instructions for the CR task (see Appendix F) and performed one block of single-task CR trials at each of the three levels of stimulus information (1, 2 and 3 bits). The 1- and 2-bit blocks consisted of six trials, and the 3-bit block consisted of 12 trials. All trials were 1 min long followed by a 1-min rest pause. Feedback for the previous trial was presented during each rest pause. A 2-min pause was given after the twelfth trial and a 5-min rest followed the last trial.

Immediately following the 5-min pause, subjects heard taped instructions for the CL(2) task (see Appendix F). They then were given 15 single-task CL(2) trials. As with the other tasks all trials were 1 min long with a 1-min pause between trials. Again, feedback was given during the rest pause on the subject's performance on the preceding trials.

The entire first session required approximately 2.75 hours.

Day 2. On Day 2 of the experiment subjects received additional single-task practice and then performed under dual-task conditions. Subjects first performed five single-task trials at each of the three levels of the CR task. The order of presentation of the three levels was the same as in Day 1. A 2-min pause was given following the third block of single-task trials. Next, the subjects received ten trials of single-task CL(2) followed by a 5-min rest pause.

Immediately following the 5-min pause, subjects listened to taped instructions for the dual-task CL(2)-CR combination (see Appendix F). They were instructed to consider both tasks as equally important. Subjects then performed one dual-task block at each of the three information levels of the CR task. Each block consisted of five trials. Following each block, the subject performed one single-task CR trial at the same information level as the immediately preceding dual-task block, followed by one single-task CL(2) trial. A 2-min pause preceded the second dual-task block, with another 2-min pause following the last pair of single-task trials. Subjects ended the session by performing one additional single-task CR trial at each level, followed by one single-task CL(2) trial. The single-task CR trials were presented in the same order as in Day 1.

All trials on Day 2 were 1 min long with a 1-min pause between trials during which feedback was given. The entire second session required approximately 2.3 hours.

Day 3. The third day of the experiment was concerned primarily with dual-task performance. Subjects first performed a pair of single-task CR trials at each of the three information levels and then two single-task CL(2) trials. The order of presentation for the CR trials was the same as that of Days 1 and 2. Next, subjects performed one block of dual-task trials at each level of the CR task. Each block was followed by a single-task CR trial at the same level as the preceding block and a single-task CL(2) trial. A 2-min pause was given before the second block of dual-task trials, and a 5-min pause followed the last pair of single-task trials. The order of presentation of the dual-task blocks and corresponding single-task CR trials was the same as that of Days 1 and 2.

Immediately following the 5-min pause, subjects again performed three dual-task blocks following the same pattern as earlier in the session. After the last dual block and its corresponding single-task trials, subjects were given a 2-min pause. As in Day 2 subjects ended the session by performing an additional single-task trial at each of the three levels of CR and finally a single-task CL(2) trial.

The entire third session required approximately 2.5 hours. All trials were 1 min long with a 1-min pause between trials during which feedback was presented concerning the subject's performance. On both Days 2 and 3 subjects were verbally reminded of the instructions for the tasks.

Results

Strategy Analysis

The fifth dual-task trial of the ME-CL combination was used to classify the subject's response strategy using the same technique as in Experiments I and II. Table 9 shows the distribution of the percentage of simultaneous responses by group. Tables 10 and 11 give similar data for the percentage of switches and the maximum number of serial responses. As is evident in these tables, the strategy used by the subjects could be easily classified as a massed, alternating, or simultaneous response strategy. A total of 11 subjects were identified as using the massed strategy. Nine were found to use an alternating strategy and six, a simultaneous strategy. It should be noted that two subjects who used a massed response strategy for the ME-CL task combination used an alternating strategy for the CR-CL(2) combination. Additionally, one subject who used the alternating strategy for the ME-CL combination used a simultaneous strategy for the CR-CL(2) combination; a second changed to a massed strategy.

Use of the CRI and H_s Measures

The Hick-Hyman Law expresses the relation between correct response time and the amount of information transmitted, H_t. As noted previously, the CRI is essentially the same as the correct response time at high levels of accuracy. Additionally, H_t is approximately equal to the amount of information presented to the subject, H_s, when the subject's accuracy is high. As shown in Table 12, the subjects made few errors on either task. Therefore, in all subsequent analyses the CRI and H_s measures were used instead of the correct response time and H_t

Purdue Pegboard Test

Performance on the Purdue Pegboard Test was analyzed to determine if manual

TABLE 9

Distribution of the Percentage of Simultaneous Responses by Group

Percentage of Switches	Group: Sim	Alt	Mass
0		8/9*	10/11
1-9		1/9	1/11
10-25			
26-40			
41-55			
56-70			
71-85	1/6		
85-99	3/6		
100	2/6		

*The numerator represents the number of subjects whose percentage of simultaneous responses was within the row limits; the denominator is the total number of subjects in the group.

TABLE 10

Distribution of the Percentage of Switches by Group

Percentage of Switches	Group		
	Sim	Alt	Mass
0	2/6*		
1-9	3/6		3/11
10-25	1/6		4/11
26-40			2/11
41-55			2/11
56-70			
71-85			
85-99		3/9	
100		6/9	

*The numerator represents the number of subjects whose percentage of switches was within the row limits; the denominator is the total number of subjects in the group.

TABLE 11

Maximum Number of Sequential Responses by Group

Maximum Number	Group: Sim	Group: Alt	Group: Mass
1	5/6*	5/9	
2-9	1/6	4/9	4/11
10-15			1/11
16-20			2/11
21-25			2/11
26-30			
31-35			1/11
36-40			1/11
41-45			
46-50			
50			

*The numerator represents the number of subjects whose maximum number of sequential responses was within the row limits; the denominator is the total number of subjects in a group.

TABLE 12

Percentage of Correct Responses as a Function of Group, Task, and Information Processing Load

Group	Task CR	Task CL(2)
	Single Task	
Massed	97.2	96.7
Alternating	96.7	95.4
Simultaneous	96.8	97.2
	Dual Task	
Massed	97.3	97.7
Alternating	97.9	96.7
Simultaneous	98.3	97.1

dexterity was related to performance on the experimental tasks. Single-hand pegboard scores did not correlate significantly ($p > .05$) with Day 3 single-task CR performance at the 3-bit level. Additionally, two-hand pegboard scores did not correlate significantly with Day 3 dual-task CR performance at the 3-bit level. Consequently, these scores were not used in any subsequent analyses.

Single-Task Performance

To minimize the effects of practice, only Day 3 single-task data were analyzed. Homogeneity of variance tests were made on all relevant data before any of the analyses reported below were conducted. None of the data violated the assumption ($p > .05$).

CL(2). A two-way (trial by group) repeated measures ANOVA was conducted on the CL(2) data. Only the main effect of trial was significant ($F_{7,\ 161} = 2.57$, $p < .02$).

CR. A three-way (group by information level by trial) ANOVA revealed a significant main effect of information level ($F_{2,\ 46} = 366.97$, $p < .0001$) and a main effect of group ($F_{2,\ 23} = 4.83$, $p < .02$). The main effect of trial was not significant nor were any interactions.

CR regression. To determine if the single-task CR data were adequately represented by the Hick-Hyman Law, a first-order regression equation was computed for each of the three response groups. The scores were averaged across subjects for each trial at each of the three levels of stimulus information. The resulting equation for the subjects who used the massed response strategy to perform the ME-CL combination was $CRI = 0.245 + .168\ H_s$. The corresponding equations for the alternating and simultaneous response groups were $CRI = 0.213 + .171\ H_s$ and $CRI = 0.204 + .149\ H_s$ respectively. The corresponding R^2 values for the three groups were .979, .985, and .985

Dual-Task Performance

The major purpose of the experiment was to determine if the between-group differences observed in Experiment I were caused by between-group differences in the duration of various information processing stages. The significant between-group differences in single-task CR performance, however, do not permit a straightforward analysis of the dual-task performance data. Therefore, several different analyses were conducted on the raw dual-task scores. Additionally, several analyses were conducted on the CR data corrected for differences in single-task performance.

Again, only Day 3 data were analyzed. Homogeneity of variance tests are reported only when the data violated the assumption.

CR (raw scores). To explore further the between-group differences found under single-task conditions, a three-way (group by processing load by stimulus information level) repeated measures ANOVA was conducted. The last trial of each dual-task block at each information level and the single-task trial which immediately preceded each dual-task block were selected for analysis. These data were found to violate the assumption of homogeneity of variance ($F_{max_{36,\ 5}}$ = 740.348, $p < .01$). Consequently, these data were transformed using the equation $x' = \log x$. The transformed scores did meet the assumption ($F_{max_{36,\ 5}} = 60.061$, $p > .05$). The main effects of processing load ($F_{1,\ 23} = 1066.38$, $p < .0001$) and stimulus information level ($F_{2,\ 46} = 507.37$, $p < .0001$) were both significant. The load by stimulus information level interaction also was significant ($F_{2,\ 46}$ = 123.67, $p < .0001$). All other effects were not significant.

CR regression analysis (raw scores). A first-order regression was performed on each response strategy group's data. The regressions were conducted on scores

averaged across subjects on each trial at each level of stimulus information. The resulting function for the massed strategy group was CRI = 1.188 + 0.181 H_s. The function for the alternating group was CRI = 1.004 + 0.153 H_s and for the simultaneous group, CRI = 1.027 + 0.168 H_s. The corresponding R^2 values were .841, .903, and .879.

Each individual subject's data also were analyzed using a first-order regression to obtain slope and intercept values. A one-way (group) ANOVA performed on the slope parameters showed no significant effect of group (p >.05). A similar one-way ANOVA performed on the intercepts also showed no significant between-group effect (p >.05).

CL(2) (raw scores). A three-way (group by stimulus information level by trial) ANOVA revealed significant main effects of trial ($F_{9, 207}$ = 2.58, p <.01) and stimulus information level of the paired CR task ($F_{2, 46}$ = 99.18, p <.0001). All other effects were not significant (p >.05)

CL(2) regression analysis (raw scores). A first-order regression was performed on the CL(2) scores. H_s was the stimulus information present in the paired CR task. The resulting functions for the massed, alternating, and simultaneous response groups were CRI = 1.165 + 0.164 H_s, CRI = 1.036 + 0.137 H_s, and CRI = 1.067 + 0.162 H_s respectively. The corresponding R^2 values were .851, .803 and .845.

CR regression analysis (difference scores). Day 3 dual-task CR scores were averaged across subjects for each trial at each of the three information levels. Single-task scores on those trials immediately preceding the dual-task blocks were each averaged across subjects at each information level. Difference scores then were computed by subtracting average single-task scores from each of

the average dual-task scores in the corresponding preceding block. Ten difference scores were obtained at each information level.

A first-order regression was computed on each group's data. The resulting functions for the massed, alternating, and simultaneous response groups were $CRI = 0.966 + 0.002\ H_s$, $CRI = 0.805 - 0.0246\ H_s$, and $CRI = 0.821 + 0.019\ H_s$. The corresponding R^2 values were .001, .201, and .101 respectively. Only the slope parameter for the alternating group was significantly different from 0.0 ($p < .02$).

Discussion

One of the most striking results of Experiment III is the generality of the Hick-Hyman Law; it provides a good description of choice reaction time data under dual-task conditions although it does not account for quite as much variance as under single-task conditions. The applicability of this law to dual-task data replicates a previous finding by Damos and Wickens (1977) who examined performance on a choice reaction time task performed alone and paired with a compensatory tracking task. The average dual-task rate of information processing in this experiment was very similar to that found in the Damos and Wickens' study under comparable dual-task conditions.

The three-way ANOVA performed on the raw CR data indicated a significant main effect of processing load. This effect may be seen very clearly in Figure 10 as a large increase in intercept from single- to dual-task conditions. Unlike the Damos and Wickens experiment this large increase in intercept cannot be due to scanning requirements because both displays were within parafoveal vision. Additionally, the increase in intercept in this experiment is approximately 500 msec greater than the increase in the Damos and Wickens experiment. Because the intercept generally is assumed to reflect the encoding and motor response factors, this increase probably reflects the time spent processing the CL(2) task and is not very interesting in its own right.

Unlike the Damos and Wickens experiment, however, this study found a reliable load by stimulus information level interaction indicating different rates of information processing under single- and dual-task conditions. An examination of the slope parameters for the three groups under dual- and single-task conditions indicates that, on the average, the rate of information processing was slower

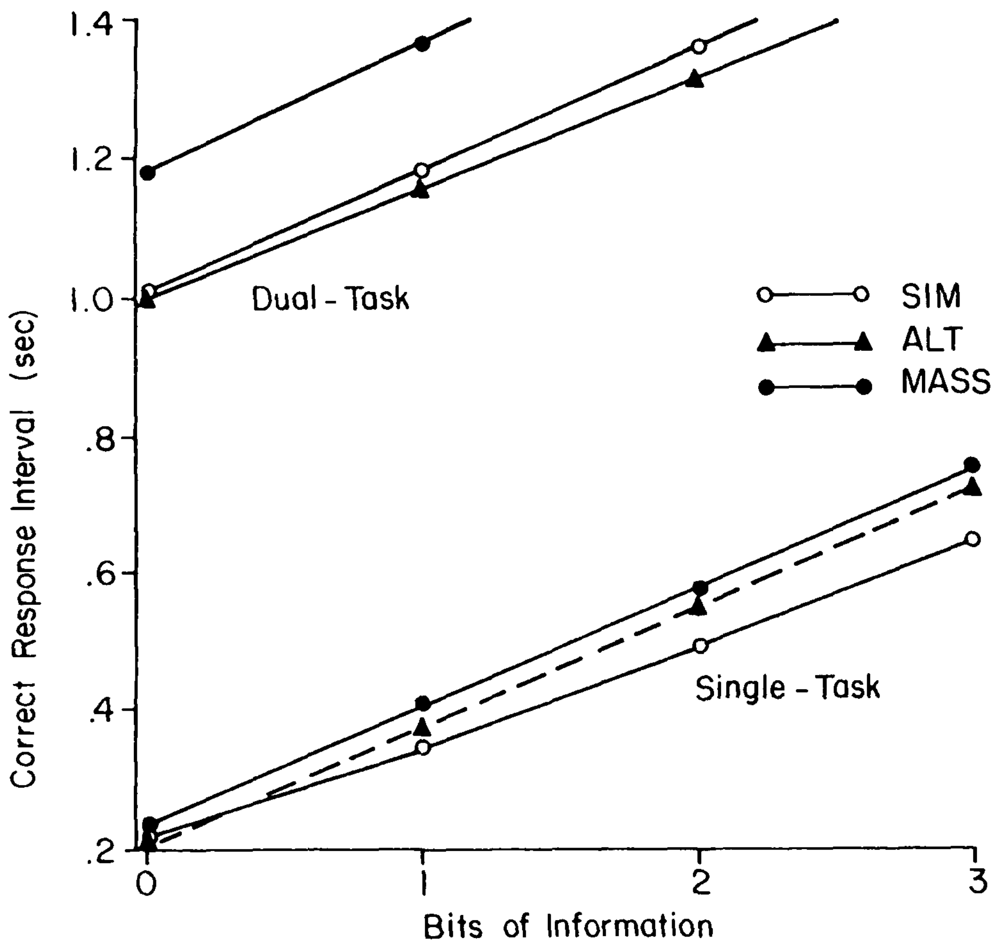

Figure 10. Graphs of the best-fitting equations for Day 3 CR performance by group and information processing load.

under dual-task conditions.

Although the ANOVA performed on the single-task CR data showed a main effect of group, the three-way ANOVA performed on both the single- and dual-task data did not find a comparable effect. This, of course, indicates that the group factor was not strong enough to "carry over" to the dual-task condition.

As noted previously, the major purpose of this experiment was to compare the rate of information processing of the three groups under dual-task as well as single-task conditions. Significant between-group differences would be evident in a significant group by stimulus information level interaction and/or a significant group by processing load by stimulus information level interaction. Both these interactions were found not to be significant. Thus, the three-way ANOVA seems to indicate that the groups process information at the same rates although the dual-task rate is slower than the single-task rate.

However, an examination on Table 13 indicates that this conclusion is not entirely warranted; the alternating response group actually has a faster rate of information processing under dual-task conditions. This fact also is reflected in the negative slope of the regression equation calculated on the difference scores. Table 13 also indicates that this was not the result of a trade-off between the CR and the CL(2) tasks because the alternating group also has the fastest rate of information processing on the CL(2) task nor was it caused by a particularly slow rate of information processing under single-task conditions; both the massed and the alternating response groups have very similar single-task processing rates. Thus, although neither of the relevant interactions were significant, the data do seem to indicate that the alternating response subjects process information under dual-task conditions much faster and perhaps differently than the other two groups.

TABLE 13

Information Processing Rates by Group, Task, and Processing Load

Group	Single-Task CR	Dual-Task CL(2)	Dual-Task CR
Massed	.168*	.164	.181
Alternating	.171	.137	.153
Simultaneous	.149	.162	.168

*Information processing rates are in bits per sec.

Finally, it should be noted that performance on the dual-task CL(2) task increased linearly as a function of the stimulus information level of the paired CR task. This indicates that the subjects were following the instruction to consider both tasks as equally important. It also indicates that the subjects were not processing information in parallel; not only did the CL(2) reaction time increase with increases in H_s, but the rate of information processing on the CR task decreased under dual-task conditions. These results may be interpreted as evidence for the single-channel model of attention. However, they also support the specific resources model (Kantowitz and Knight, 1976; Wickens, 1980) because both the CR and the CL(2) tasks appear to use the same resource pools suggested by Wickens (1980). Thus, this model would predict the observed increase in CRI for the CL(2) task as a function of H_s on the paired task and the decrease in information processing rate from single- to dual-task conditions for the CR task.

CONCLUSION

The overall impression left by these three studies is that of consistent individual differences in multiple-task performance that are related to the response strategy used to perform a discrete task combination. Experiment I provides the most conclusive evidence for these differences. It also indicates that subjects using the massed response strategy generally are poor timesharers who probably should not perform jobs requiring rapid processing of information from multiple sources. Both the alternating and the simultaneous response strategy subjects appear to be good timesharers. Although no conclusive statements can be made, the data appear to indicate that the alternating subjects may be better time-sharers than the simultaneous response subjects for two reasons. First, they showed little evidence of a disruption in performance when asked to change strategy, indicating some flexibility in processing and, second, they actually performed slightly better with a simultaneous response strategy than the true simultaneous subjects themselves.

Experiments II and III were designed to identify the source of the differences observed in Experiment I. Experiment II indicated that the differences cannot be attributed to differences in multiple-limb coordination, cognitive styles, or cerebral lateralization. These results, however, should be regarded with some caution because of the small number of alternating response subjects in the experiment.

Experiment III shed little additional light on the source of the observed differences. No significant between-group differences were found which would indicate general differences in information processing rate or differences in dual-task information processing. However, the fact that the rate of information

processing was faster under dual- rather than single-task conditions for the alternating response strategy group is suggestive.

Because some evidence for consistent individual differences in multiple-task performance was found in these experiments, future research should concentrate on replicating Experiment I and identifying the source of these differences. Specifically, between-group differences in information processing rates should be explored further by pairing a CR task with other tasks hypothetically requiring different resource pools and with a more difficult version of the CL task used in Experiment III. Experiment I also should be enlarged to determine if the simultaneous response subjects can adopt an alternating strategy as easily as the alternating subjects adopted a simultaneous strategy. Finally, between-group differences should be examined in environments which are more representative of the real world.

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APPENDIX A

Day 1 Instructions

Memory Task Instructions

The task you are to perform is a memory task. You will perform this task with your right hand. Your first finger will correspond to the number 1, the second to the number 2, the third finger to the number 3, and the little finger to the number 4. You are to keep your fingers on the keys at all times. Do not use your thumb to respond.

In this task digits will be presented one at a time. You must remember the digit that is currently being displayed and respond to the preceding digit. As soon as you respond, the current digit will be erased and a new one presented. For instance (show figure), suppose the first stimulus is a three. Because there are no preceding stimuli, simply push button one. This is just a signal to the computer that you have seen the first stimulus. It has no relation to the stimulus. After you have seen the second stimulus, a two, press three for the preceding stimulus. After you have seen the third stimulus, a one, press two for the second stimulus, etc. Digits will be erased regardless of whether you hit the correct key or not.

At the end of each trial your performance will be summarized and displayed on the screen. The display will look like this (show figure). The ME in the top line identifies the task as the memory task. The CRT is the correct response time. This value represents your average time between correct responses. Any mistakes you make increase this value. The Total Responses indicates the number of responses you made regardless of whether they were right or wrong. The Percent Correct indicates the percentage of

correct responses. Your job is to make the CRT as small as possible while maintaining 95% accuracy or better.

Are there any questions?

Classification Task Instructions

The task you are to perform is a classification task. On the display in front of you, you will see two digits side by side. The digits may vary on two dimensions: size and name. For example, you may see a small seven and a large six. Sometimes the digits will be alike on both dimensions (such as two small sevens), sometimes on one dimension (such as a large seven and a large six), and sometimes they will be different on both dimensions (such as a small seven and a large six). You are to indicate the number of dimensions on which the stimuli are alike. You will indicate your response using only your left hand. To indicate that they are alike on both dimensions, press the right key with your first finger. To indicate that they are alike on one dimension and different on the other, press the middle key with your second finger. To indicate that they are different on both dimensions, press the left key with your third finger. The pair will be erased from the screen regardless of whether you hit the correct key or not. You are to keep your fingers on the keys at all times. Do not use your thumb to respond.

At the end of each trial your performance will be summarized and displayed on the screen. The display will look like this (show figure). The CL in the top line identifies the task as the classification task. The CRT is the correct response time. This value represents your average time between correct responses. Any mistakes you make increase this value. The Total Responses indicates the number of responses you made regardless of whether they were right or wrong. The Percent Correct indicates the percentage of right responses to the total number of responses. Your job

is to make the CRT as small as possible while maintaining 95% accuracy or better.

Are there any questions?

Memory-Classification Instructions

Now you will perform both tasks simultaneously. The memory task will be performed with the right hand; classification, with the left. On the right side of the screen you will see a digit between one and four for the memory task. On the left side of the screen you will see a pair of numbers between five and eight for the classification task. To start the memory task, hit the left key of your right-hand keyboard as you did under single-task conditions. The stimuli will be erased from the screen regardless of whether your responses were correct or incorrect. You are to consider the tasks as equally important.

Your job is to respond to the stimuli as quickly and accurately as possible. On each trial you should try to obtain a smaller CRT than on the preceding trial while maintaining 95% or better accuracy on both tasks. At the end of each trial your CRT, percent accuracy, and total number of responses will be displayed for both tasks on the screen so you can see how well you are doing. The display will look like this (show figure). All values will be calculated as in the single-task trials.

Are there any questions?

APPENDIX B

Day 2 Instructions

Massed to Alternating Response Strategy Group

Today you will perform the same two tasks, memory and classification, as you did yesterday. The last time you performed these two tasks concurrently, you chose to make several responses to one task before switching to the other. Today, I would like you to alternate responding to each task. That is, you should make only one response to each task before you respond to the other. If at any time you find that you have made several responses to one of the tasks, please switch to the other task immediately and resume alternating your responses between the tasks.

On each trial you are to make the CRT as small as possible while maintaining an accuracy of 95% or better. At the end of each trial your CRT, percent accuracy, and total number of responses will be displayed on the screen so you can see how well you are doing. The display will look just as it did yesterday. All values will be calculated as in the single-task trials. Three bonuses will be given to people in your group. A $10 bonus will be given to the person with the best overall average CRT on both tasks. A $6 and a $4 bonus will be given to the persons with the second- and third-best averages.

Are there any questions?

<u>Alternating to Alternating Response Strategy Group</u>

Today you will perform the same two tasks, classification and memory, as you did yesterday. The last time you performed these two tasks concurrently, you chose to alternate your responses between the two tasks. Today I would like you to use the same response strategy. That is, alternate your responses between the two tasks just as you did before.

On each trial you are to make the CRT as small as possible while maintaining an accuracy of 95% or better. At the end of each trial your CRT, percent accuracy, and total number of responses will be displayed on the screen so you can see how well you are doing. The display will look just as it did yesterday. All values will be calculated as in the single-task trials. Three bonuses will be given to people in your group. A $10 bonus will be given to the person with the best overall average CRT on both tasks. A $6 and a $4 bonus will be given to the persons with the second- and third-best averages.

Are there any questions?

Massed to Simultaneous Response Strategy Group

Today you will perform the same two tasks, memory and classification, as you did yesterday. The last time you performed these two tasks concurrently, you chose to make several responses to one task before switching to the other. Today, I would like you to respond to the two tasks simultaneously. That is, you should depress the key corresponding to the correct answer to the classification task at the same time you depress the key corresponding to the correct answer to the memory task. If at any time you find that you have not been responding simultaneously, please begin responding simultaneously again immediately. Make sure to depress the response keys at the same time.

On each trial you are to make the CRT as small as possible while maintaining an accuracy of 95% or better. At the end of each trial your CRT, percent accuracy, and total number of responses will be displayed on the screen so you can see how well you are doing. The display will look just as it did yesterday. All values will be calculated as in the single-task trials. Three bonuses will be given to people in your group. A $10 bonus will be given to the person with the best overall average CRT on both tasks. A $6 and a $4 bonus will be given to the persons with the second- and third-best averages.

Are there any questions?

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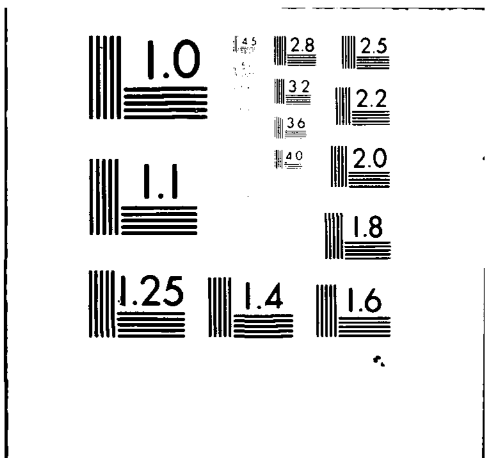


MICROCOPY RESOLUTION TEST CHART

<u>Alternating to Simultaneous Response Strategy Group</u>

Today you will perform the same two tasks, classification and memory, as you did yesterday. The last time you performed these two tasks concurrently, you chose to alternate your responses between the two tasks. Today, I would like you to respond to the two tasks simultaneously. That is, you should depress the key corresponding to the correct answer to the classification task at the same time you depress the key corresponding to the correct answer to the memory task. If at any time you find that you have not been responding simultaneously please begin responding simultaneously again immediately. Make sure you depress the response keys at the same time.

On each trial you are to make the CRT as small as possible while maintaining an accuracy of 95% or better. At the end of each trial your CRT, percent accuracy, and total number of responses will be displayed on the screen so you can see how well you are doing. The display will look just as it did yesterday. All values will be calculated as in the single-task trials. Three bonuses will be given to people in your group. A $10 bonus will be given to the person with the best overall average CRT on both tasks. A $6 and a $4 bonus will be given to the persons with the second- and third-best averages.

Are there any questions?

Simultaneous to Simultaneous Response Strategy Group

Today you will perform the same two tasks, classification and memory, as you did yesterday. The last time you performed these two tasks concurrently, you chose to respond to the two tasks simultaneously Today I would like you to use the same response strategy. That is, respond to both tasks simultaneously just as you did before. Make sure you depress the response keys at the same time.

On each trial you are to make the CRT as small as possible while maintaining an accuracy of 95% or better. At the end of each trial your CRT, percent accuracy, and total number of responses will be displayed on the screen so you can see how well you are doing. The display will look just as it did yesterday. All values will be calculated as in the single-task trials. Three bonuses will be given to people in your group. A $10 bonus will be given to the person with the best overall average CRT on both tasks. A $6 and a $4 bonus will be given to the persons with the second- and third-best averages.

Are there any questions?

APPENDIX C

Biography

I. Did you ever play a musical instrument? _____Yes _____No

If yes, which one(s) ____

____

How many years did you play and on the average how many hours per week did you spend? ____

____

Do you still play now? _____Yes _____No

II. Do you ever compete in any of the following sports?

gymnastics _____Yes _____No

diving _____Yes _____No

high jump _____Yes _____No

skijumping _____Yes _____No

judo _____Yes _____No

aikido _____Yes _____No

skydiving _____Yes _____No

III. Did you ever own a motorcycle? _____Yes _____No

If yes, how many miles a year did you ride? ____________

APPENDIX D

Handedness Questionnaire

With which hand do you

1. Draw	L	Both	R
2. Write	L	Both	R
3. Remove the top card from a deck of cards when you are shuffling	L	Both	R
4. Use a bottle opener	L	Both	R
5. Throw a baseball to hit a target	L	Both	R
6. Use a hammer	L	Both	R
7. Use a toothbrush	L	Both	R
8. Use a screwdriver	L	Both	R
9. Use an eraser on a piece of paper	L	Both	R
10. Use a tennis racket	L	Both	R
11. Use a scissors	L	Both	R
12. Hold a match when striking it	L	Both	R
13. Stir a liquid	L	Both	R
14. On which shoulder do you rest a bat before swinging?	L	Both	R
15. With which foot do you kick a ball?	L	Both	R

With which hand do the following write with?

Mother	L	Both	R
Father	L	Both	R
Siblings	L	Both	R
	L	Both	R
	L	Both	R
	L	Both	R

APPENDIX E

Tracking Instructions

Single-Task Tracking Instructions

On the display in front of you, you will see a tracking task that looks like this (show figure). You are to keep the two small bars centered on the line. To do this, you must move the control stick either to the left or the right. If you want the circle to move to the right, move the stick to the right. If you want the circle to move to the left, move the stick to the left.

The distance between the center of the bars and the vertical line is the error. At the end of each trial your average error will be displayed so you can see how well you are doing. The display will look like this (show figure). On each trial you are to try to beat your performance on the preceding trial.

All trials in this experiment will be 1 min long. There will be a 1-min break between trials. A buzzer will sound before each trial. The trial will start 3 sec after the buzzer stops. The intercom will be on throughout the experiment, so you can communicate with me at any time.

Are there any questions?

Dual-Task Tracking Instructions

You will now perform both tracking tasks simultaneously. The display will look as shown in the drawing (show figure). The tracking task that is displaced to the right will be controlled by your right hand. The one that is displaced to the left will be controlled by your left hand. The two tasks are to be considered equally important. All trials will be 60 sec long with a 70-sec break between trials. Do not favor one task over the other. About 1 min after the end of each trial your performance will be summarized and your average error will be displayed on the screen. The display will look like this (show figure). All values will be calculated as in the single-task trials. Your job is to obtain the lowest error score possible on each trial. Are there any questions?

APPENDIX F

Choice Reaction Time Instructions

The task you are to perform is a choice reaction time task. You will perform this task with your right hand. For this task, you will use the second and third rows of keys. The keys will be numbered from left to right. On the third row, your first finger will correspond to the number 1, your second finger to the number 2, your third finger to the number 3, and your little finger to the number 4. On the second row your first finger will correspond to the number 5, your second finger to the number 6, your third finger to the number 7, and your little finger to the number 8. You are to keep your fingers on the third row of keys at all times, except when responding on the second row. Do not use your thumb to respond.

In this task digits will be presented one at a time. You must respond to the digit that is currently being displayed. As soon as you respond, the current digit will be erased and a new one presented. For instance, suppose the first digit is a three. You must press the button corresponding to three. Digits will be erased regardless of whether you hit the correct key or not. Some trials will only require that you use two fingers. Other trials will require that you use four fingers, and some trials will require that you use all eight keys. You will be instructed before each trial as to how many and which fingers are to be used in the next trial.

At the end of each trial your performance will be summarized and displayed on the screen. The display will look like this. The CR at the top identifies the task as the choice reaction time task. The CRT is the correct response time. This value represents your average time between correct responses. Any

mistakes you make increase this value. The Total Responses indicates the number of responses you made regardless of whether they were right or wrong. The Percent Correct indicates the percentage of correct responses to the total number of responses. Your job is to make the CRT as small as possible while maintaining 95 percent or better accuracy.

Are there any questions?

Classification (2) Task Instructions

The task you are to perform is a classification task. On the display in front of you, you will see two figures side by side. The figures include triangles, squares and rectangles. The figures may vary on two dimensions: shape and height. For example, you may see a small triangle and a large square. Sometimes the figures will be alike on both dimensions (such as two small triangles), sometimes on one dimension (such as a large triangle and a large square), and sometimes they will be different on both dimensions (such as a small triangle and a large rectangle). You are to indicate the number of dimensions on which the stimuli are alike. You will indicate your response using only your left hand. To indicate that they are alike on both dimensions, press the right key with your first finger. To indicate that they are different on both dimensions, press the left key with your third finger. The pair will be erased from the screen regardless of whether you hit the correct key or not. You are to keep your fingers on the keys at all times. Do not use your thumb to respond.

At the end of each trial your performance will be summarized and displayed on the screen. The display will look like this (show figure). The CL in the top line identifies the task as the classification task. The CRT is the correct response time. Any mistakes you make increase this value. The Total Responses indicates the number of responses you made regardless of whether they were right or wrong. The Percent Correct indicates the percentage of right responses to the total number of responses. Your job is to make the CRT as small as possible while maintaining 95% or better accuracy.

Are there any questions?

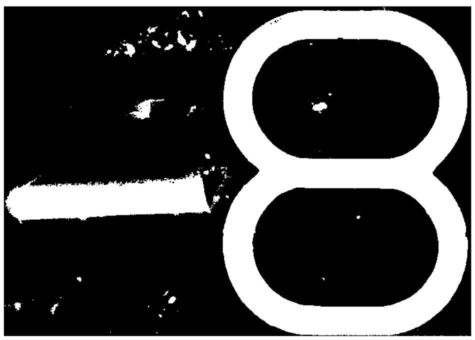
Classification - Choice Reaction Time Instructions

Now you will perform both tasks simultaneously. On the left side of the screen you will see a pair of figures for the classification task. On the right side of the screen you will see a digit for the choice reaction time task. Before each trial you will be reminded by the experimenter as to which keys will be used in the choice reaction time task. The tasks are to be considered equally important.

The stimuli will be erased from the screen regardless of whether your responses were correct or incorrect. At the end of each trial your CRT, Total Responses, and Percent Correct will be displayed on the screen for both tasks. The display will look like this (show figure). All values will be calculated as in the single task trials.

Your job is to attain as small a CRT score as possible while maintaining 95% or better accuracy for both tasks. Remember, do not favor one task over the other.

Are there any questions?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